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THANKSGIVING 1966 AIR POLLUTION EPISODE IN THE EASTERN UNITED STATES

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Consumer Protection and Environmental Health Service

THANKSGIVING 1966
AIR POLLUTION EPISODE
IN THE EASTERN UNITED STATES

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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THANKSGIVING 1966
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INTRODUCTION

In recent years adverse health effects resulting from acute air pollution episodes have been dramatically demonstrated. In these cases excess illness due to sharp increases in air pollution concentrations was sudden in onset and in some cases fatal in outcome. The best known cases are those in the Meuse Valley, Belgium[1] (1930); Donora, Pennsylvania[2] (1948); London[3,4] (1952 and 1953); New York City[5] (1953); London[6] (1962); and New York City[7] (1963). Excess deaths over normal expectancy ranged from 17 in Donora to 4000 in the 1952 London smog. Sensational and tragic as these acute episodes are, health authorities are even more concerned today with the slow, insidious effects on human lungs and other organs by air pollution levels that are much lower, but are continued every day, year after year.

The weather is a major factor in the creation of air pollution problems. When air pollution episodes occur, they result not so much because of a great or sudden increase in the output of pollutants, but rather because of adverse weather conditions, which trap the pollutants in a mass of stagnant air. Even during normal weather conditions, the daily accumulation of wastes in a community's air varies with weather factors as well as with the rate at which pollutants are discharged into the atmosphere. Air pollution has become a ubiquitous threat to our health and welfare because of the ever-increasing emissions of air contaminants into the never-increasing atmosphere. The result is an increased exposure of large segments of the population.

Meteorologists of the Air Resources Cincinnati Laboratory (Environmental Science Services Administration) at the National Center for Air Pollution Control issues advisories* or forecasts of extended periods of restricted natural ventilation, i.e., atmospheric stagnation. This report documents one such forecasted stagnation period which occurred in the Eastern United States during late November 1966. During the stagnation period, air quality deteriorated significantly. An analysis of air quality data from a number of cities showed elevated

*Forecasts are issued at the National Meteorological Center in Suitland, Maryland.

levels of selected pollutants for the week preceding the episode even though an advisory was not issued, because the area affected did not fit the criteria for extent and duration concurrently.

This publication documents the Thanksgiving 1966 Air Pollution Episode in the Eastern United States in terms of daily meteorology and ambient air quality for the weeks immediately before, during, and after the episode.

The first section presents the episode's meteorology in a technical description of the development, progress, and breakup of the stagnating high that caused the episode. A more general discussion of meteorological factors that act to disperse, or not to disperse, the various pollutants that contaminate the atmosphere is included in an appendix.

The section on air quality describes the sources and possible health effects of the air contaminants. The actual day-by-day levels of the various pollutants are presented graphically and daily meteorology is correlated with the pollutant concentrations.

NARRATIVE OF EPISODE'S METEOROLOGY

Occasionally a high-pressure system becomes almost motionless over some part of the United States and tends to interrupt the usual cycle of ventilation. As a consequence, the usual daily afternoon dispersion and dilution (see appendix for a general discussion of these terms) are diminished, and pollutants may accumulate to high concentrations over a period of several days.

This section of the report describes one such stagnating high, which caused the Thanksgiving 1966 Episode. The development, progress, and breakup of this system are documented on a day-to-day basis.

On November 20, a surface high-pressure area, which had been moving steadily eastward across the United States, was centered over New York State (Figure 1). This high was classed as "cold" since, at upper levels* the temperature was relatively low compared to temperatures of surrounding air. Figure 1 shows that over New York State the temperature at the 500-millibar (mb) level was -25°C. The same chart shows that an intrusion of 10°C warmer air appeared over the north-central states. The wind pattern carried this warmer air eastward. The replacement of the cold air over the surface high by warm air was largely responsible for the ensuing high-air-pollution-potential episode.

On November 21 (Figure 2), the center of the surface high moved on into upper New England. This area of light winds, i.e., poor horizontal ventilation, became elongated from northeast to southwest. In response to the sea level isobaric pattern, surface winds were blowing clockwise around the center of the high with moderate northeasterly winds along the eastern seaboard and strong southwesterly winds over the upper Great Lakes region. At the 500-mb level the warmer air had moved eastward from the north-centr ' states to a position over the Great Lakes.

On November 22 (Figure 3), the surface high remained in the same general location, although it continued to elongate to the northeast and southwest.

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*Weather charts are prepared twice daily showing wind direction and speed, temperature, and height of the level aloft, where the air pressure is 500 millibars. The approximate height of this level is 18,000 feet.

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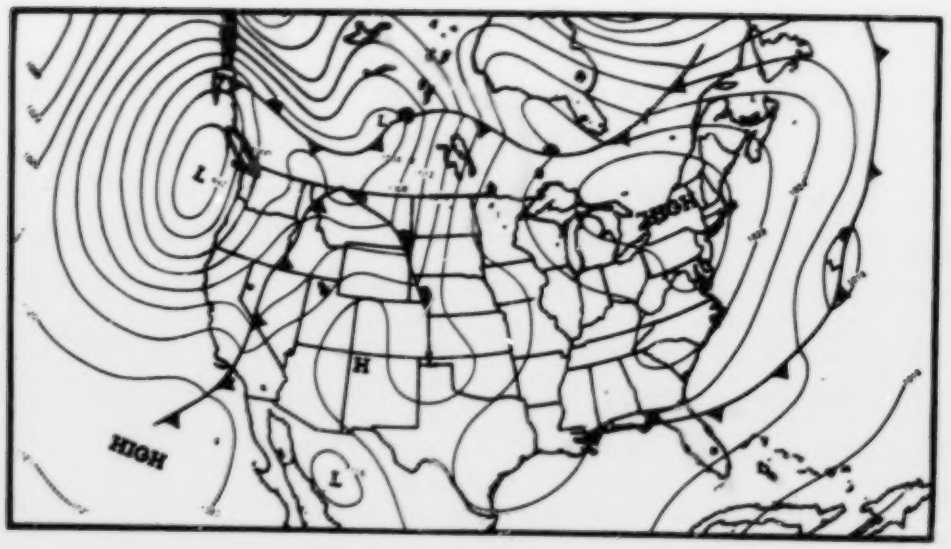


Figure 1A. Surface weather map, Sunday, November 20, 1966.

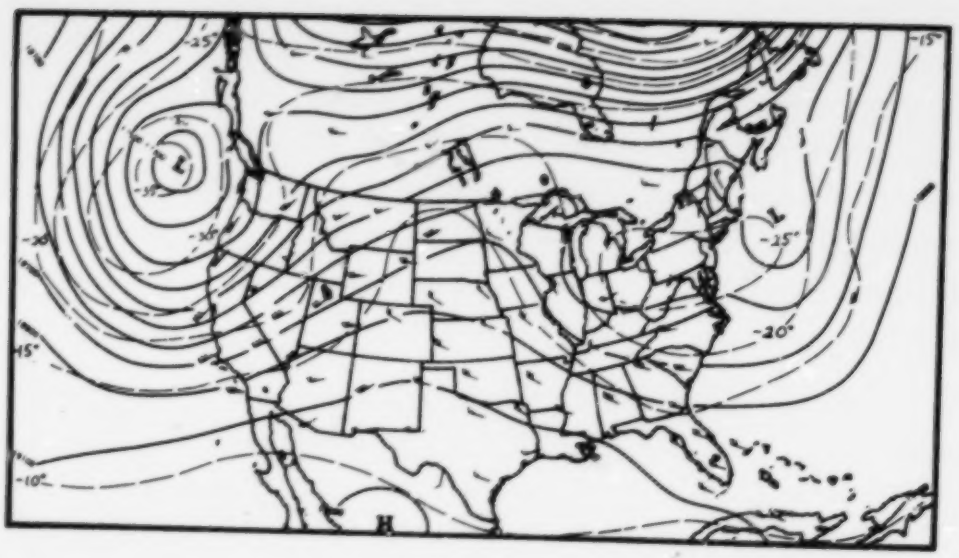


Figure 1B. Upper level (500 mb) weather map, Sunday, November 20, 1966.

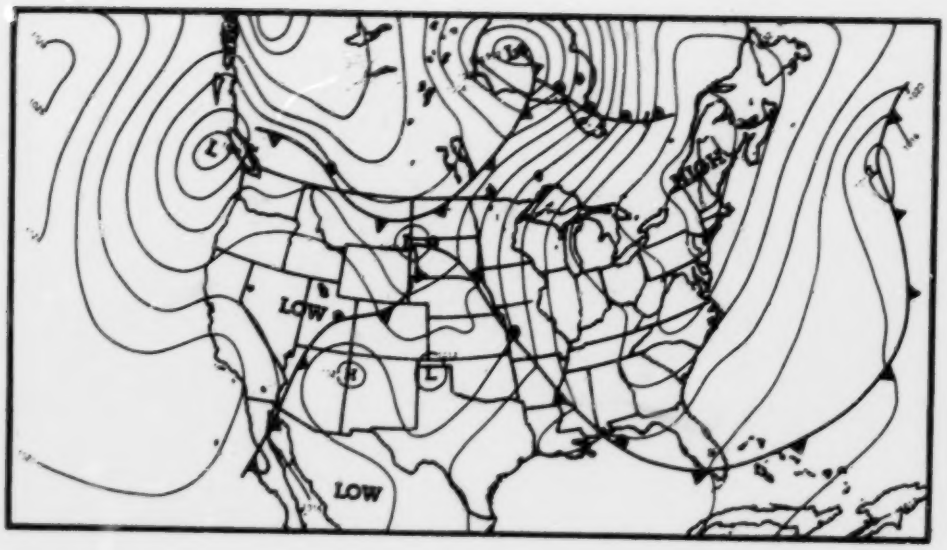


Figure 2A. Surface weather map, Monday, November 21, 1966.

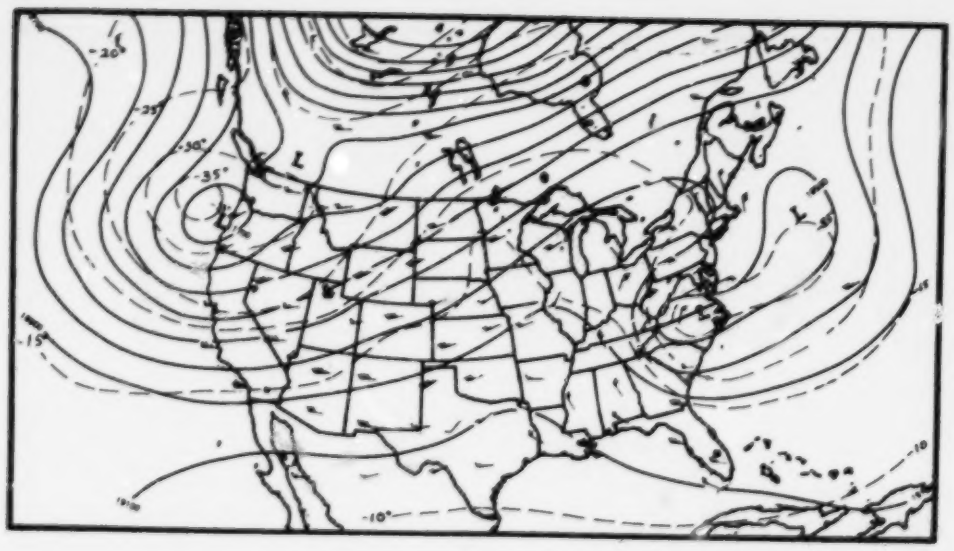


Figure 2B. Upper level (500 mb) weather map, Monday, November 21, 1966.

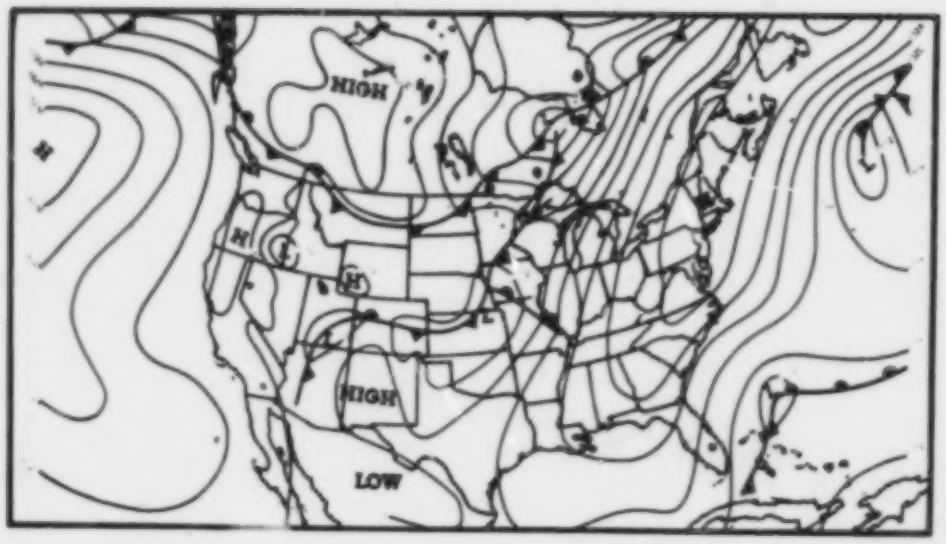


Figure 3A. Surface weather map, Tuesday, November 22, 1966.

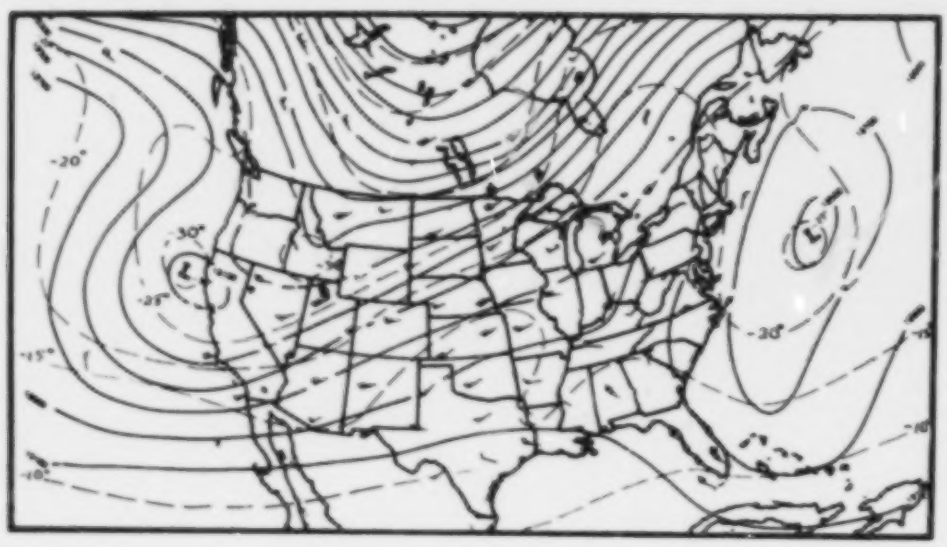


Figure 3B. Upper level (500 mb) weather map, Tuesday, November 22, 1966.

It extended along the Atlantic seaboard from Newfoundland to Virginia. At the 500-mb level over New England and southward, the air temperature had warmed to above -20°C. The spread of this warm air aloft began to cause restriction of vertical dispersion.

On November 23 (Figure 4), continued elongation of the surface high resulted in two high-pressure centers, which were connected by a ridge across New England. On the west side of the elongated high, moderate southwesterly winds occurred ahead of an advancing cold front. At the 500-mb level (Figure 4) the warm temperatures continued to spread east and south. The warming of air at the upper levels had, by November 23, caused the reclassification of the high to "warm." Ventilation in the vertical direction was restricted by this upper-level warming.

These meteorological conditions occur often, but are usually followed by the passage of a cold front with accompanying brisk winds and an influx of cleaner air. In the November 1966 case the forecast indicated that the cold front approaching from the west would be delayed, and an advisory of high air pollution potential was issued for areas A and B in Figure 5.

On November 24, Thanksgiving Day (Figure 6), the two surface highs, one east of Newfoundland and the other over northern Georgia and Alabama, were still joined by a ridge of high pressure across New England. The cold front moving across southern Canada had stalled along the St. Lawrence Valley, but a wave on this front was developing in the vicinity of Iowa. With the expected approach of the Iowa disturbance, it appeared that the western part of the forecast area (A in Figure 5) would have better ventilation, and the advisory for area A was discontinued. However, because of the development of the high to the south, the advisory of high air pollution potential was extended in that direction to include area C (Figure 5).

On November 25 the surface high over the Southeast had moved to near New Orleans (Figure 7). The frontal wave over Iowa developed rapidly and was moving over the Great Lakes. The ridge over New England was being displaced seaward. At 500 mb, colder air had returned to the Great Lakes region. With the projected eastward movement of the Great Lakes storm, and the movement of the clean air behind it to the east and south, the advisories for the remaining areas, B and C, were discontinued as of 7:00 p.m. E.S.T.

On November 26 (Figure 8) the cold front, which had moved through the Great Lakes region the previous day, passed off-shore into the Atlantic. The weather map again showed a high over the New England states extending southward, but the high could not be considered as stagnant because it had

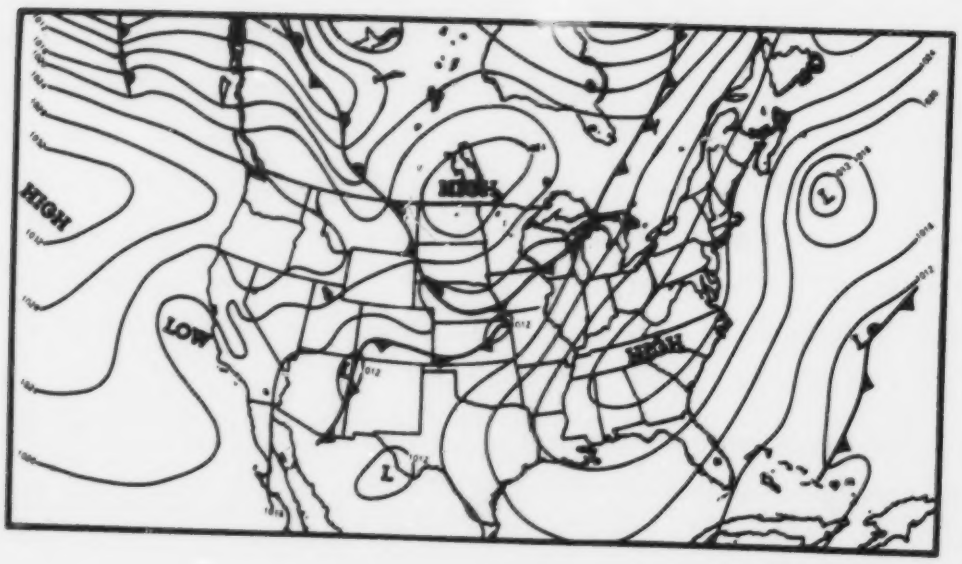


Figure 4A. Surface weather map, Wednesday, November 23, 1966.

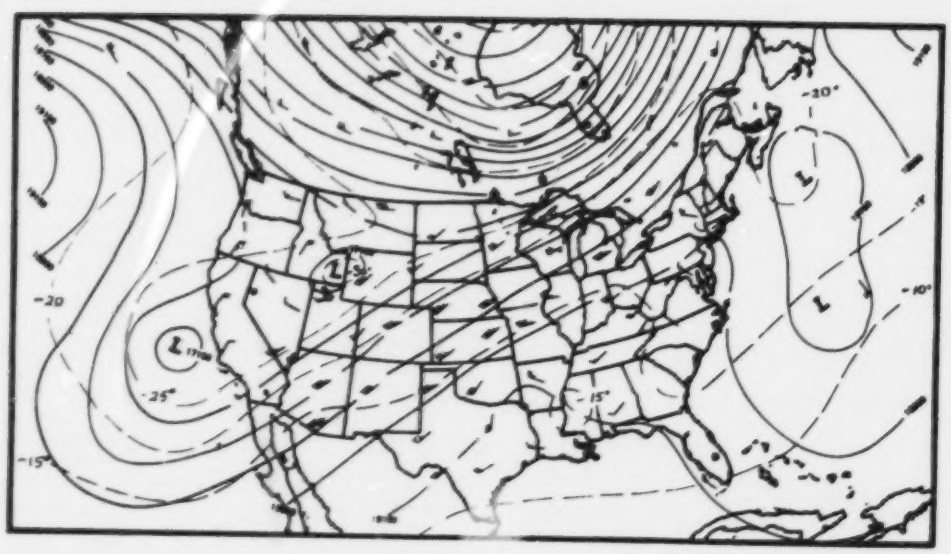
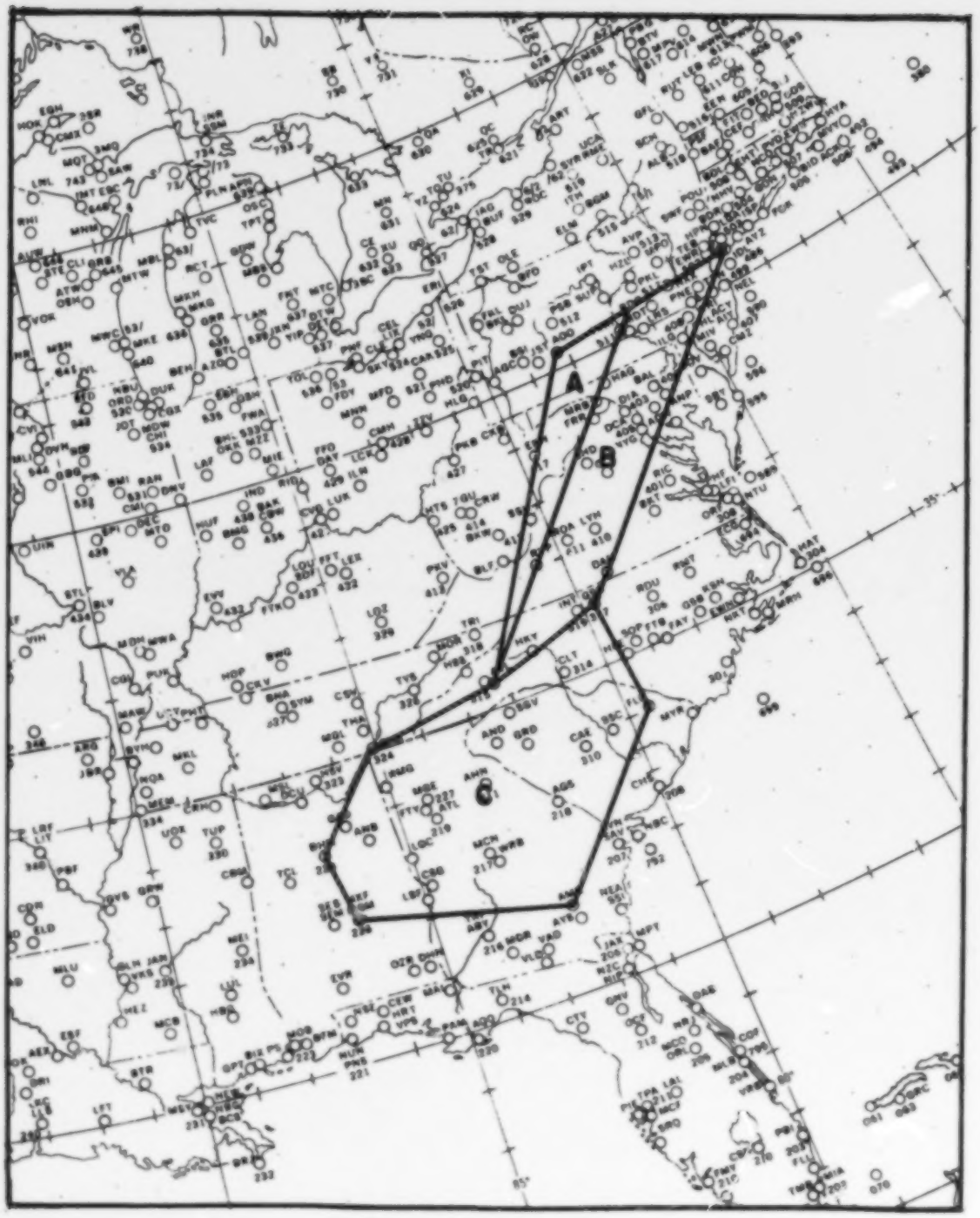


Figure 4B. Upper level (500 mb) weather map, Wednesday, November 23, 1966.



ADVISORY NUMBER 73

Begin high air pollution potential for Areas A and B, 1200 EST November 23, 1966.
Begin high air pollution potential for Area C, 1200 EST, November 24, 1966.

End high air pollution potential for Area A, 1300 EST, November 24, 1966.
End high air pollution potential for Areas B and C, 1900 EST, November 25, 1966.

Sent with Advisory Message of 1220 EST, November 25, 1966: Although atmospheric dispersion will improve this afternoon, the pollution that has accumulated in east coast cities will be dispersed gradually until a cold front passes during the night.

Figure 5. High-air-pollution-potential forecast areas, November 23 - 25, 1966.

Figure 6A. Surface weather map, Thursday, November 24, 1966.

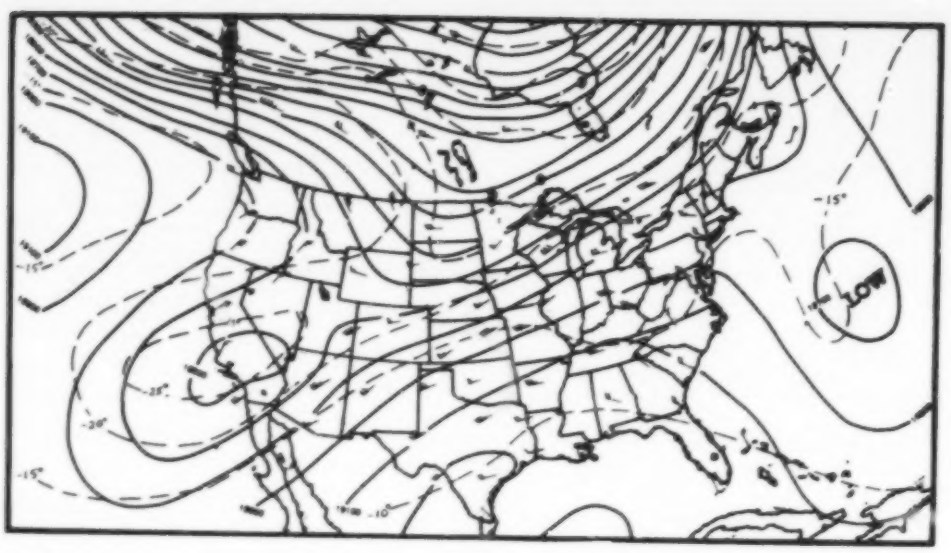


Figure 6B. Upper level (500 mb) weather map, Thursday, November 24, 1966.

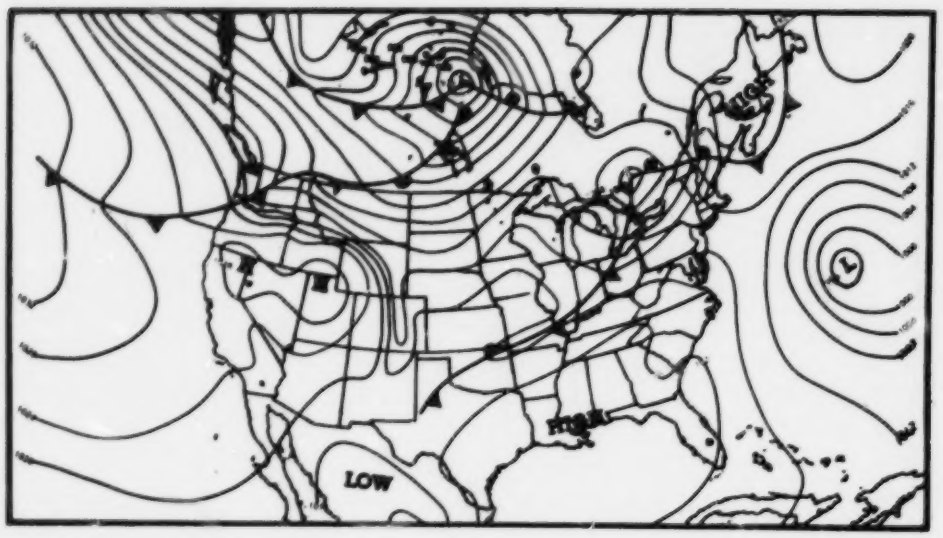


Figure 7A. Surface weather map, Friday, November 25, 1966.

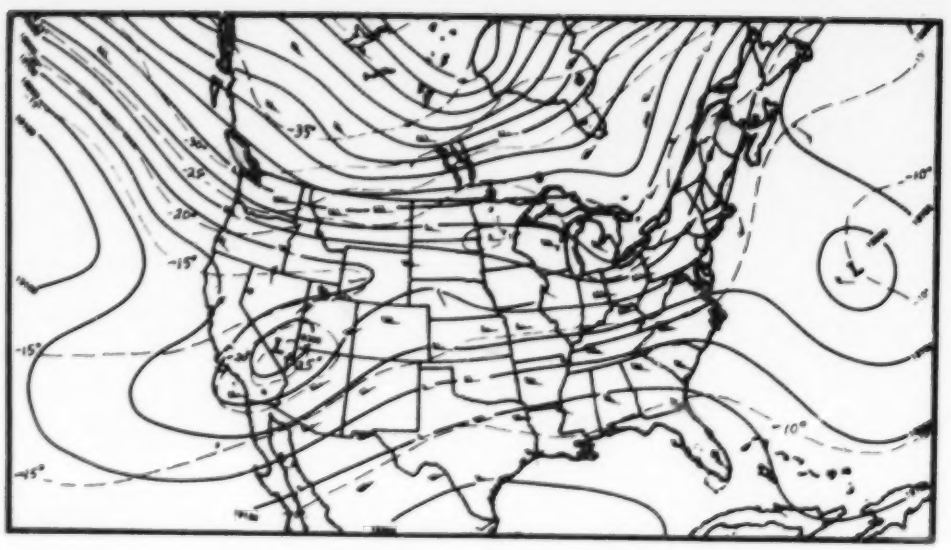


Figure 7B. Upper level (500 mb) weather map, Friday, November 25, 1966.

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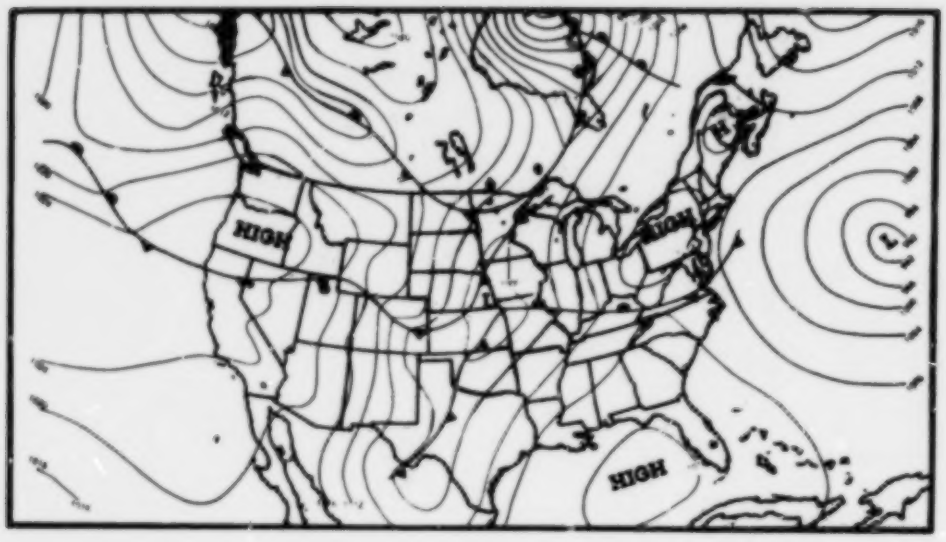

Figure 8A. Surface weather map, Saturday, November 26, 1966.

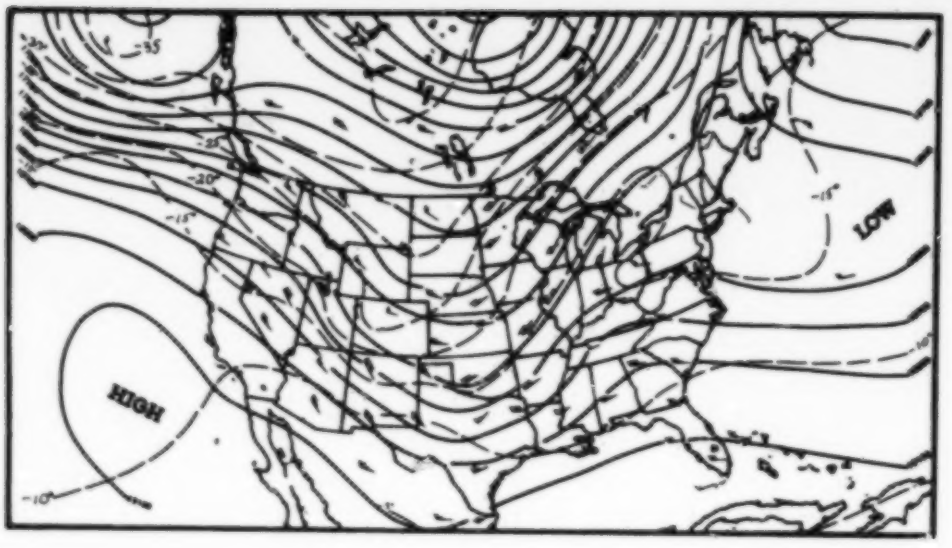

Figure 8B. Upper level (500 mb) weather map, Saturday, November 26, 1966.

just formed and extensive storm systems to the west threatened its continued existence. The high that had been over New Orleans had been displaced offshore to the southeast so that it, too, presented no threat of high air pollution potential.

Table 1 presents meteorological data of selected cities during the period from November 13 through November 30. The data shown include the average daily temperature, which is computed as the mean of the daily maximum and minimum temperatures. The cloud-cover column shows the average observed daytime cloud cover estimated to tenths. The afternoon mixing depth is an estimate of the height to which convective currents rise during the most active period in the afternoon. These estimates are made using upper air temperature data obtained by radiosonde observations. Since upper air data are not available in the immediate vicinity of Birmingham, Boston, and Philadelphia, the general pattern of the mixing depths was analyzed and extrapolated values were assigned. At Washington, D.C., the upper air data were obtained at Dulles Airport and were used with surface temperatures from Washington National Airport. The average wind speed is the average of the speed at each thousand feet, including the surface, up to the height of the afternoon mixing depth. The column labeled "Ventilation" is the product of the afternoon mixing depth and the average wind speed, and is considered as the flow through a column 1 meter wide. The resultant wind direction is the vector sum of eight surface wind observations spaced through a 24-hour period. It indicates the direction of displacement of the surface air in the vicinity of the designated city. The average surface wind speed is the average of 8 hourly observations per day at 3-hour intervals.

These parameters are correlated with air quality data in the next section of this report, to show how adverse meteorological conditions permitted the concentrations of air pollutants to reach high levels.

Table 1. METEOROLOGICAL DATA FOR SELECTED CITIES DURING THE NOVEMBER 1966 AIR POLLUTION EPISODE

Pittsburgh, Pennsylvania (Greater Pittsburgh Airport)

Date		Average temp.	Cloud cover (tenths)	Afternoon mixing depths (meters)	Average wind speed (m/s) through mixing depth	Ventilation (m^3/s)	Resultant wind direction	Average surface wind speed (m.p.h.)
Nov.	13	38	2	974	3.5	3410	NE	6.9
	14	40	0	795	7.7	6120	WNW	6.5
	15	36	4	816	2.6	2120	NNE	5.5
	16	42	8	474	6.9	3270	S	8.8
	17	53	9	904	11.2	10120	SSW	8.8
	18	52	9	242	8.5	2060	WSW	15.5
	19	34	7	1217	9.2	11190	NW	10.9
	20	32	2	837	5.8	4860	ENE	6.9
	21	39	0	1019	4.9	4990	E	7.9
	22	39	5	638	M	M	ESE	6.3
	23	45	8	769	7.1	5460	S	6.5
	24	51	9	319	6.2	1978	SW	8.8
	25	53	10	303	6.2	1876	SW	12.5
	26	44	7	890	M	M	SW	5.5
	27	56	10	M	M	M	SE	10.1
	28	38	10	b	7.2	M	WNW	13.5
	29	28	10	697	10.7	7460	SSW	14.7
	30	30	10	501	M	M	W	12.5

Birmingham, Alabama (Municipal Airport)

Nov.	13	55	4	600	2.5	1500	E	6.8
	14	56	2	1150	5.0	5750	NE	3.3
	15	55	2	M	4.0	M	ESE	4.3
	16	54	0	1330	8.5	11305	S	3.7
	17	63	3	500	7.0	3500	S	6.8
	18	63	3	1600	2.0	3200	WSW	4.9
	19	60	4	1250	5.0	6250	N	4.3
	20	55	3	850	2.0	1700	NE	3.3
	21	54	10	850	5.0	4250	E	9.2
	22	51	6	750	4.0	3000	E	8.1
	23	53	2	1000	5.0	5000	E	3.2
	24	55	3	900	2.0	1800	SSE	1.6
	25	58	6	1100	6.0	6600	SW	4.5
	26	65	10	900	9.0	8100	SSW	6.6
	27	54	10	350	10.0	3500	WSW	15.0
	28	43	2	1500	16.0	24000	WNW	17.3
	29	41	0	1500	14.0	21000	WNW	13.4
	30	43	3	M	M	M	NNW	5.2

Table 1. (continued). METEOROLOGICAL DATA FOR SELECTED CITIES DURING THE NOVEMBER 1966 AIR POLLUTION EPISODE

Boston, Massachusetts (Logan International Airport)

Date		Average temp.	Cloud cover (tenths)	Afternoon mixing depths (meters)	Average wind speed (m/s) through mixing depth	Ventilation (m^3/s)	Resultant wind direction	Average surface wind speed (m.p.h.)
Nov.	13	42	0	1200	11.0	13200	NNW	16.8
	14	39	5	1290	6.0	7740	NE	12.9
	15	39	1	900	9.5	8550	NNW	16.1
	16	38	6	1100	6.5	7150	S	10.5
	17	54	9	1610	10.5	16905	SW	14.7
	18	56	10	100	7.0	700	SW	13.1
	19	45	3	1100	15.0	16500	NW	19.1
	20	34	0	1200	6.0	7200	NNW	9.2
	21	38	0	1150	4.0	4600	NNE	9.5
	22	37	0	850	7.0	5950	NNE	8.2
	23	40	2	500	4.0	2000	NW	6.2
	24	42	5	300	1.5	450	ENE	6.0
	25	45	8	470	2.0	940	E	8.5
	26	51	10	250	8.0	2000	NE	9.5
	27	50	10	450	3.5	1575	NNE	11.5
	28	49	10	200	5.0	1000	ENE	12.7
	29	50	8	750	7.0	5250	S	11.4
	30	43	5	M	M	M	W	14.4

Philadelphia, Pennsylvania (International Airport)

Nov.	13	43	2	1300	6.5	8450	N	10.9
	14	40	0	900	5.0	4500	N	7.9
	15	41	3	1100	9.0	10800	N	11.2
	16	41	5	750	4.0	3000	SSW	6.8
	17	53	9	500	4.0	2000	SW	8.1
	18	54	10	400	5.0	2000	SW	9.5
	19	44	6	1200	11.0	13200	N	12.4
	20	36	0	1000	5.0	5000	NE	9.2
	21	38	0	1150	5.0	5750	NE	7.9
	22	39	0	900	2.0	1800	NE	5.5
	23	39	4	600	3.0	1800	W	4.5
	24	50	7	600	5.0	3000	W	5.0
	25	53	9	250	5.0	1250	WSW	5.3
	26	52	5	900	8.5	7650	N	7.3
	27	46	8	700	5.5	3850	E	5.9
	28	50	10	150	6.0	900	SSE	15.4
	29	39	8	2000	9.5	19000	SSW	11.4
	30	36	6	M	M	M	W	11.9

Table 1. (continued). METEOROLOGICAL DATA FOR SELECTED CITIES DURING THE NOVEMBER 1966 AIR POLLUTION EPISODE.

New York, New York (La Guardia Field)

Date	Average temp.	Cloud cover (tenths)	Afternoon mixing depths (meters)	Average wind speed (m/s) through mixing depth	Ventilation (m^3/s)	Resultant wind direction	Average surface wind speed (m.p.h.)
Nov. 13	43	0	1117	7.6	8490	N	14.4
14	41	1	911	7.1	6460	N	9.3
15	44	3	1409	7.7	10830	NNW	13.7
16	44	6	1065	2.8	2985	SSE	9.5
17	55	9	577	8.2	4730	SW	10.8
18	57	10	270	5.7	1540	WSW	12.2
19	48	5	1138	11.0	12520	N	18.3
20	36	0	774	5.0	3870	NE	10.8
21	41	0	1094	4.4	4820	NE	6.6
22	41	0	682	2.7	1840	NE	6.8
23	46	3	759	3.3	2505	SW	5.0
24	52	5	347	4.1	1420	NE	3.9
25	54	8	469	6.2	2910	SSE	7.3
26	52	5	164	5.2	853	N	8.6
27	50	7	671	2.3	1541	E	6.0
28	54	10	650	9.8	6370	SE	15.5
29	44	8	1437	10.6	15250	SSW	13.1
30	40	5	M	M	M	W	13.2

Washington, D.C. (National Airport)

13	45	4	1291	5.2	6720	N	10.5
14	43	0	957	2.9	2775	NW	6.5
15	46	3	1047	11.3	11840	NNW	9.5
16	45	6	850	7.9	6710	S	7.9
17	55	7	499	2.1	1048	S	7.5
18	57	8	533	7.2	3835	SSW	6.9
19	50	6	1199	10.0	11990	NNW	13.4
20	38	1	1138	4.9	5580	NNE	7.0
21	41	5	1181	4.1	4850	NE	8.5
22	41	0	1261	0.9	1137	N	3.6
23	43	3	601	2.6	1560	S	4.2
24	51	7	1038	6.5	6750	SSW	3.7
25	58	10	191	M	M	S	5.2
26	52	1	1556	M	M	N	5.9
27	51	6	M	M	M	ESE	6.0
28	49	10	b	7.2	M	S	12.1
29	40	9	2296	6.8	15620	SSW	11.6
30	39	7	2056	M	M	W	11.5

[b] Frontal passage caused mixing depth discontinuity.

[M] Data missing.

AIR QUALITY

Pollutants, after being released into the atmosphere, are dispersed or diluted in different ways according to meteorological conditions and the physical height at which they are released. Because of this the discussion of air quality during the episode considers each pollutant or group of pollutants separately. It must be recognized that the concentration of the pollutants is, in part, directly related to the site of the sampler and that the site is not uniform for all of the cities presented in this report.

GASEOUS POLLUTANTS

Sulfur Dioxide

Fossil fuels such as coal and petroleum contain sulfur, which, when burned, is converted to sulfur dioxide and, to a lesser degree, sulfur trioxide. Since fossil fuels are burned abundantly in the United States for heating and the generation of electric power, pollution of the atmosphere with the oxides of sulfur is widespread, especially in Eastern and Mid-Western cities. Petroleum refineries, smelting plants, coke processing plants, sulfuric acid manufacturing plants, and smoldering coal refuse banks are other major sources of sulfurous pollution.

Considerable evidence points to the fact that sulfur oxide pollution very likely contributes to the development of and aggravates existing respiratory disease in humans. In the documented air pollution disasters, large numbers of people became ill and many died. All episodes had common factors - they occurred in heavily industrialized areas during relatively brief periods of anticyclonic weather, with a resulting buildup of pollutants.

Mean levels of sulfur dioxide (SO_2) are presented graphically for the period November 13 through 30, 1966, in Figure 9. During the week preceding the episode, significant rises were noted in mean concentration levels for short periods in most of the cities. This is especially evident for the period November 14 through November 18. Emission of sulfur dioxide from space-heating sources was not a significant factor in the increased sulfur dioxide levels because of relatively high temperatures during both periods. In general, the higher concentrations of sulfur dioxide during the first period were due to

shallow afternoon mixing depths. In a few cases, the sulfur dioxide levels were apparently sustained by a change in wind direction that afforded more direct transport from major sources even though surface wind speeds were relatively strong.

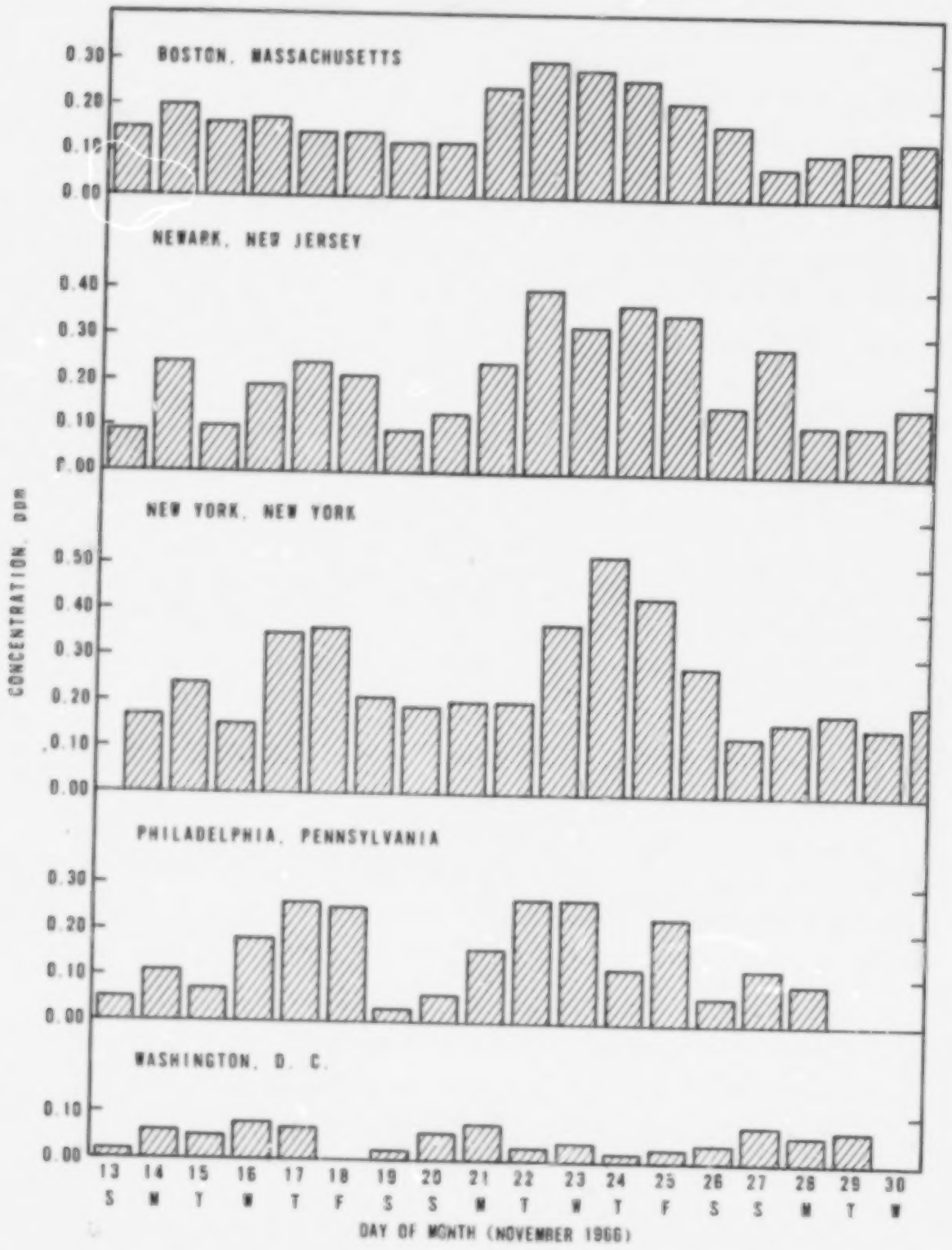

Figure 9. Sulfur dioxide, 24-hour mean values, November 13 - 30, 1966, Boston, Mass.; Newark, N. J.; New York City, N.Y.; Philadelphia, Pa.; and Washington, D.C.

Sulfur dioxide measurements showed a general upward trend on November 21, with peak concentrations occurring between November 22 and November 24. The afternoon mixing depth and average wind speeds both at the surface and aloft were low for this period. Thus, the rise in SO_2 levels during the period was due to the accumulation of sulfurous pollution from high- and low-level sources. Improved atmospheric dispersion on November 25 resulted in the gradual dilution of the polluted air. As the cold front passed through on the night of November 25, the levels fell off rapidly.

Mean concentrations of pollutants give only a partial picture of a city's air quality. Some knowledge of the variability in concentrations is equally important. The daily pattern, which is the basic cycle of interest here, is the result of interactions between source strength, the dilution capacity of the atmosphere, and, in some cases, photochemical reactions.

Figure 10 presents the diurnal variation of sulfur dioxide levels for selected days during the two periods of poor pollutant dispersion. The general pattern of SO_2 levels is evident — a peak during the morning hours and a minimum in the afternoon hours, which, although lower than the early morning peaks, is still high when compared to more normal days.

The high hourly peak averages, i.e., 0.97 ppm in New York City on November 24, are well above the level that the Public Health Service has indicated to be acceptable for the protection of health and welfare.[8] Researchers[9] in New York City, assessing consequences of the Thanksgiving episode, found an increase of approximately 24 deaths per day during the period November 24 through 30.

Peak sulfur dioxide concentrations in New York City during the Thanksgiving episode were not as high as in previous episodes, i.e., the November-December 1962 Air Pollution Episode.[10] During the more recent episode, SO_2 levels would have been higher except for the following reasons:

1. The weather was relatively warm and thus space heating was at a minimum.

2. Many industrial plants and commercial establishments were not operating because of the holiday weekend.

3. Some process industries voluntarily reduced SO_2 emissions, and power generating units switched to low-sulfur fuels wherever possible.

Since Boston is not far outside the area defined by the advisory, its weather patterns were very similar to those of the cities included in the stagnation area.

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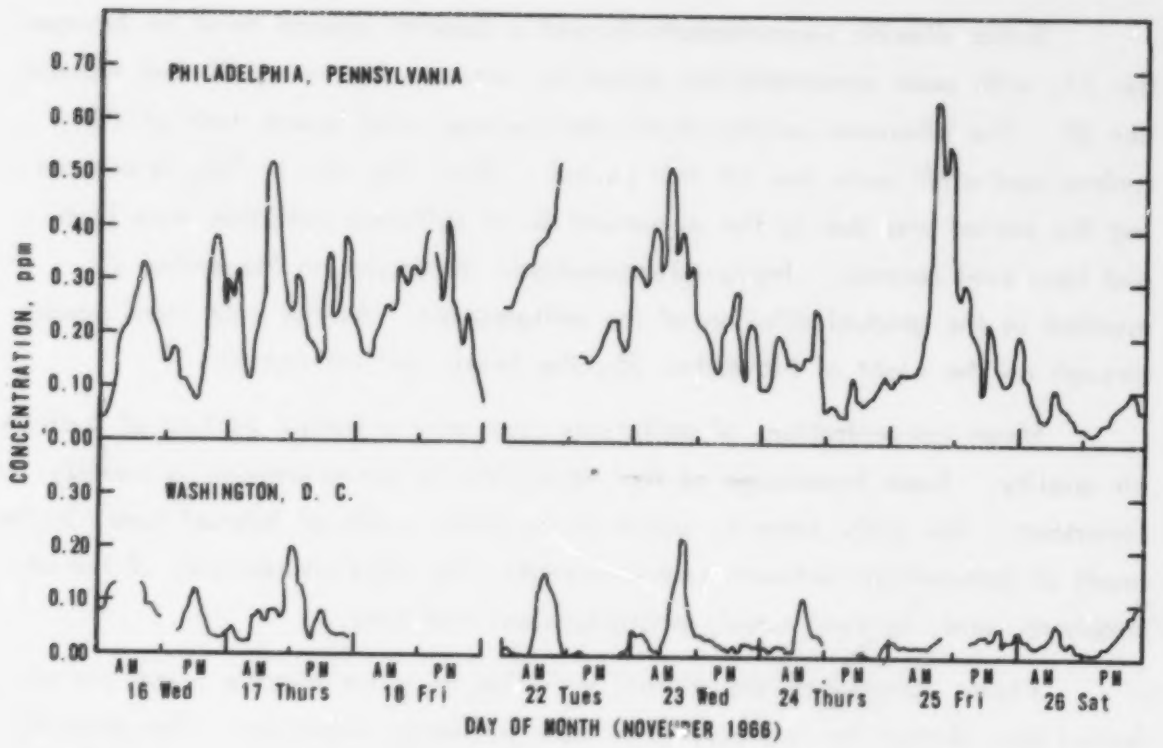


Figure 10A. Sulfur dioxide (diurnal variations) November 16 - 18, and November 22 - 26, 1966, Philadelphia, Pa., and Washington, D.C.

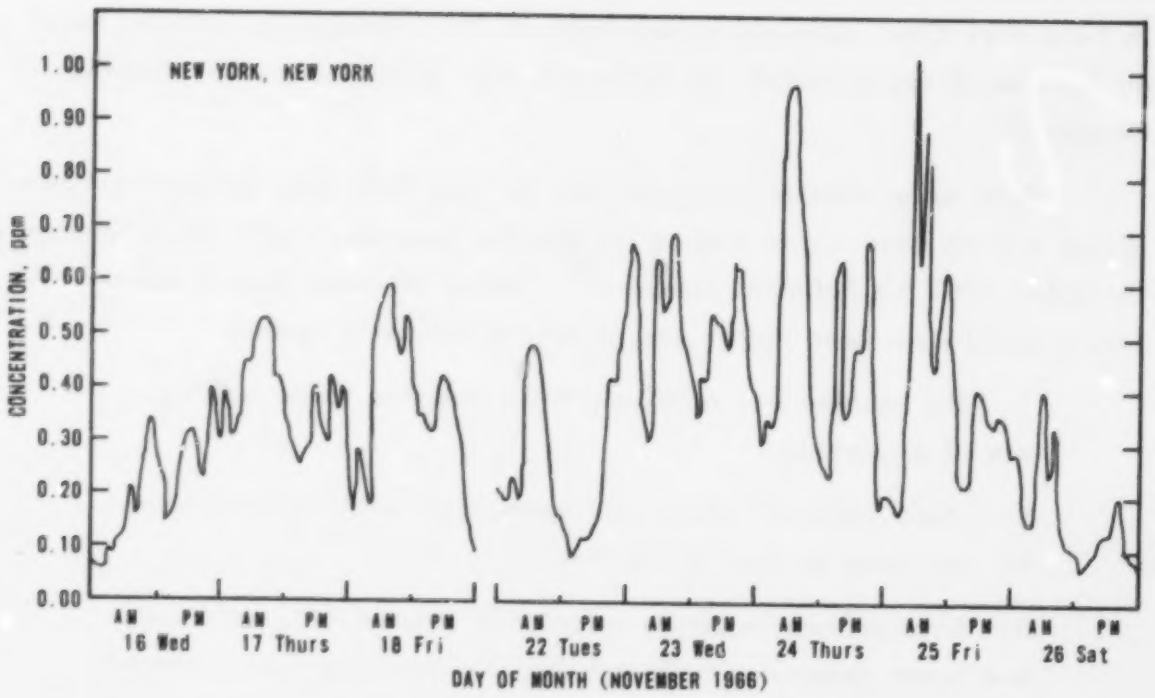


Figure 10B. Sulfur dioxide (diurnal variations) November 16 - 18, and November 22 - 26, 1966, New York City, N.Y.

Oxides of Nitrogen

Nitric oxide (NO) and nitrogen dioxide (NO_2) are produced by any high temperature combustion process in which air is used as an oxygen source. Relative levels of these oxides of nitrogen are also influenced by atmospheric reactions that convert nitric oxide to nitrogen dioxide, with the rate of conversion related to the intensity of solar radiation, much as in the production of photochemical smog. Nitrogen dioxide, most toxic of the oxides of nitrogen, is an important component in the complex of reactions producing photochemical smog.

Figure 11 presents the mean nitric oxide levels for the 2-week period encompassing the episode. Peak values for nitric oxide occurred from November 23 to 25, then fell to normal levels with the arrival of the cold front. Mean nitrogen dioxide levels (Figure 12), although lower than those of nitric oxide, exhibited the same general pattern.

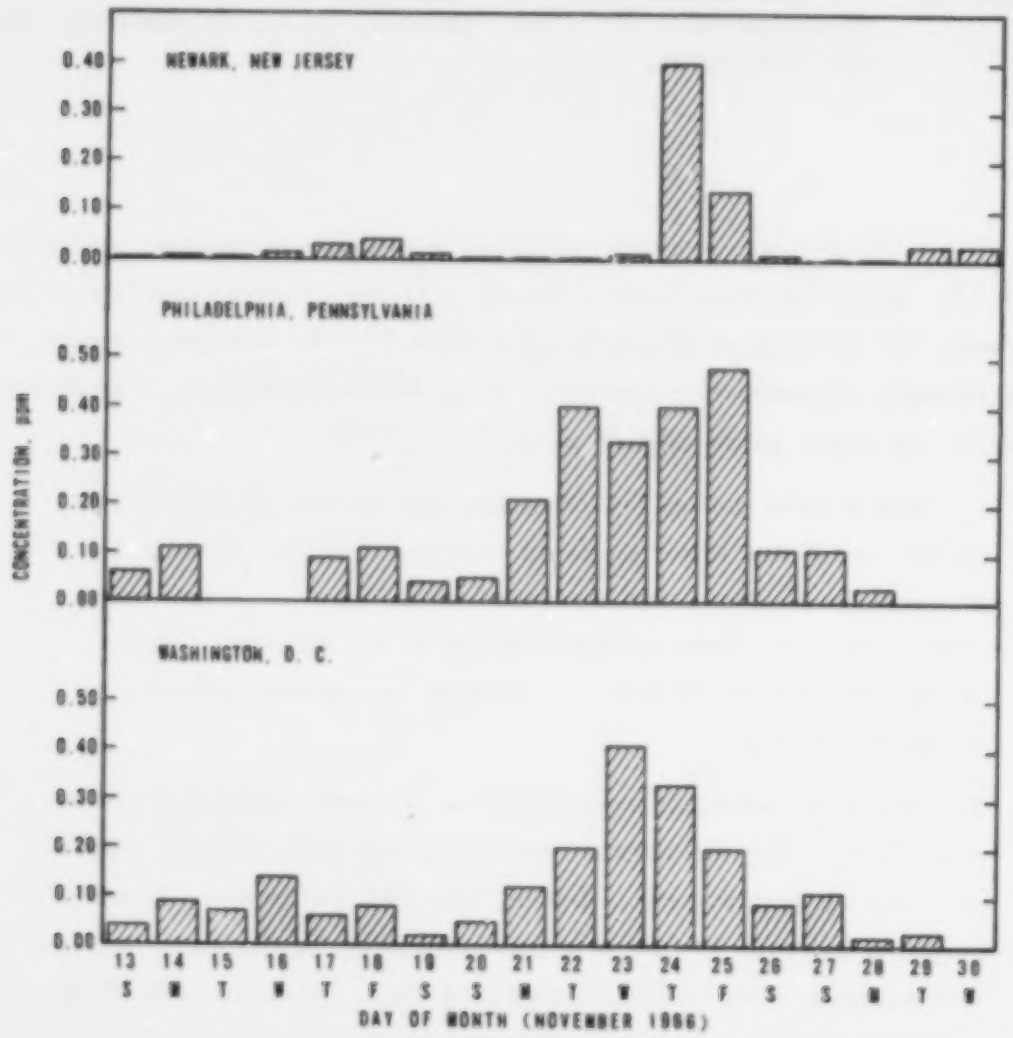


Figure 11. Nitric oxide (NO) 24-hour mean values November 13 - 30, 1966, Newark, N.J.; Philadelphia, Pa.; and Washington, D.C.

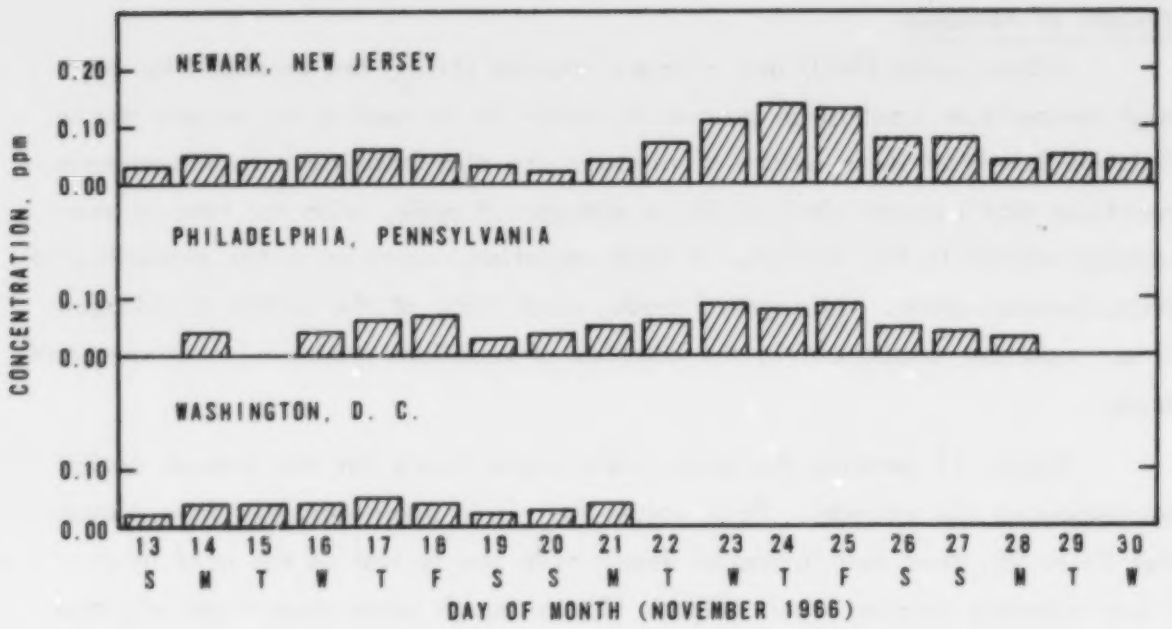

NEWARK, NEW JERSEY
PHILADELPHIA, PENNSYLVANIA
WASHINGTON, D. C.
0.20
0.10
0.00
0.10
0.00
0.10
0.00
CONCENTRATION, ppm
13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
S M T W T F S S M T W T F S S M T W
DAY OF MONTH (NOVEMBER 1966)

Figure 12. Nitrogen dioxide (NO_2) 24-hour mean values November 13 - 30, 1966, Newark, N.J.; Philadelphia, Pa.; and Washington, D.C.

Nitric oxide concentrations exhibited a pronounced diurnal variability (Figure 13), reflecting three cyclic factors: (1) the dilution capacity of the atmosphere, (2) the rate of photochemical conversion to nitrogen dioxide, and (3) the strength of combustion sources. These factors combined to produce three features in the nitric oxide diurnal pattern:

1. The minima during the afternoon are attributed to maximum conversion of the nitric oxide to nitrogen dioxide, enhanced atmospheric dilution, and decreased emissions, i.e., less automobile traffic. These minima existed in the afternoon hours during the advisory period even though atmospheric dilution was extremely limited.

2. The high overnight concentrations of nitric oxide are due to a reversal of the influences from source strength, dilution capacity, and conversion rate. During late fall and winter, levels begin to increase in late afternoon and peak in the mid- to late-evening hours. On Thanksgiving Day, November 24, Philadelphia's peak hourly nitric oxide level of 1.83 ppm occurred between 11 p.m. and midnight.

3. The characteristic morning peak was a result of the increased emissions associated with the beginning of the day's activities. The low inversion that frequently forms overnight confines increased morning emissions and further accentuates morning concentrations. With the breakup of the inversion, the mixing volume increases and the ambient concentration begins to decline even though emissions may continue at relatively high rates.

Levels of nitric oxide at Philadelphia and Washington, D.C., during the November 16 through 18 period were much lower than during the episode. Although conditions for conversion of nitric oxide to nitrogen dioxide by photochemical reactions were similar and mixing depths were extremely shallow during the two periods, higher surface wind speeds account for the lower nitric oxide concentrations in the first period.

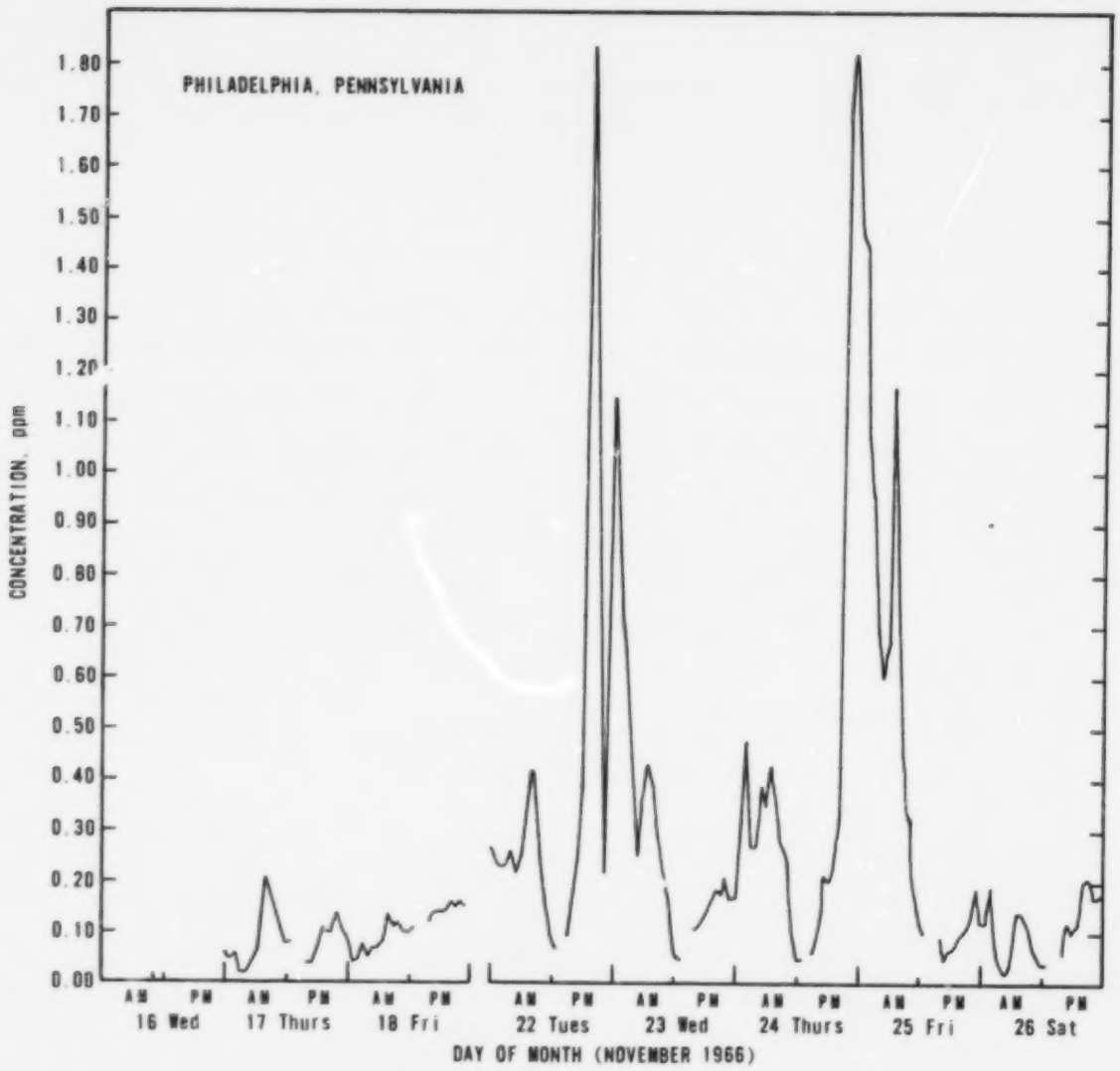


Figure 13A. Nitric oxide (diurnal variations), November 16 - 18, and November 22 - 26, 1966, Philadelphia, Pa.

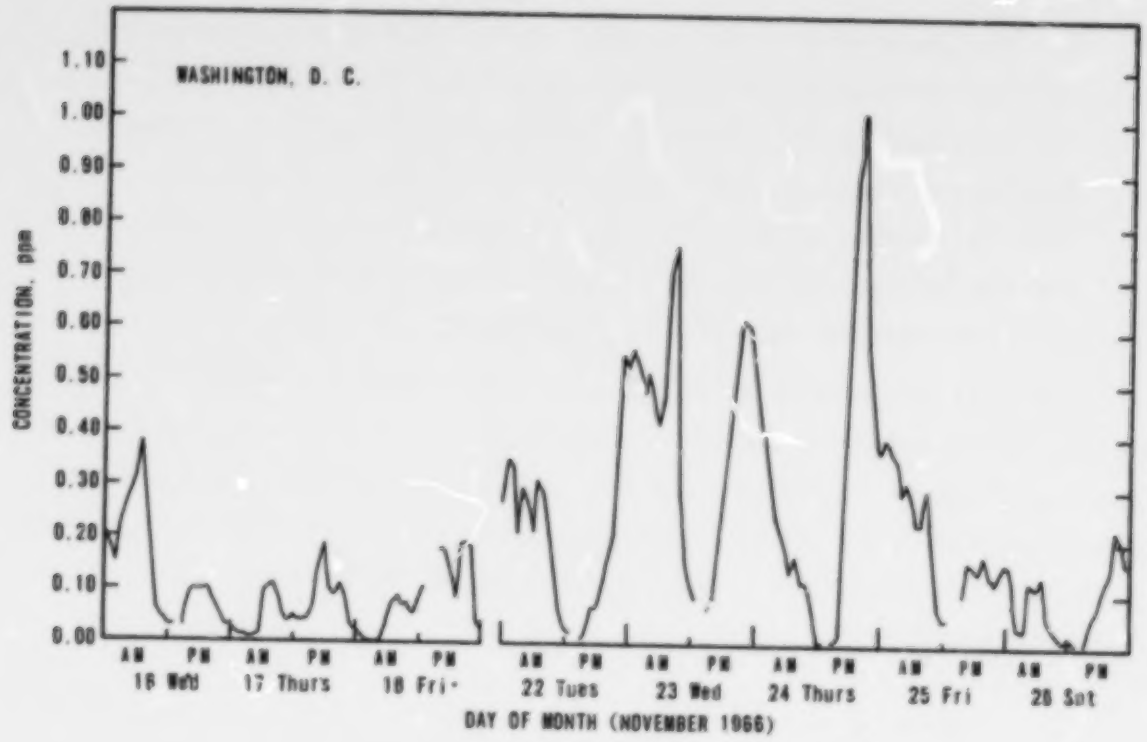


Figure 13B. Nitric oxide (diurnal variations), November 16 - 18, and November 22 - 26, 1966, Washington, D.C., and Philadelphia, Pa.

The features in the diurnal pattern of variation for nitrogen dioxide levels (Figure 14) are not as pronounced as the nitric oxide pattern because of the smoothing effect of the photochemical conversion of nitric oxide to nitrogen dioxide. However, the conversion process contributes to the afternoon concentration and sustains the nitrogen dioxide level when the dilution conditions are usually best.

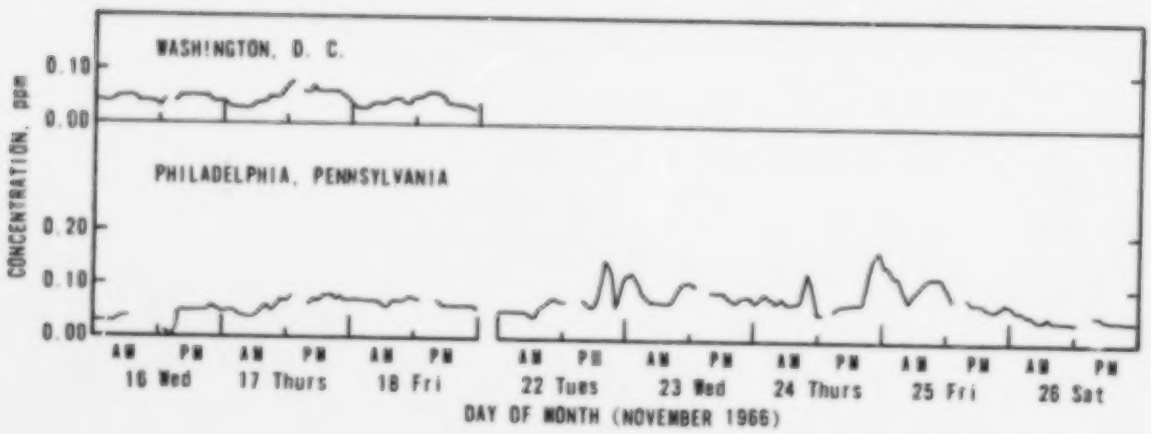

WASHINGTON, D. C.
0.10
0.00
PHILADELPHIA, PENNSYLVANIA
CONCENTRATION, ppm
0.20
0.10
0.00
AM PM AM PM AM PM AM PM AM PM AM PM AM PM AM PM
16 Wed 17 Thurs 18 Fri 22 Tues 23 Wed 24 Thurs 25 Fri 26 Sat
DAY OF MONTH (NOVEMBER 1966)

Figure 14. Nitrogen dioxide (NO_2) (diurnal variations) On November 16 - 18, and November 22 - 26, 1966, Washington, D.C. and Philadelphia, Pa.

Total Hydrocarbon

Gaseous hydrocarbon compounds in the atmosphere consist of stable hydrocarbons such as methane, which do not participate in atmospheric photochemical reactions, and reactive hydrocarbons such as olefins and aldehydes, which are, in effect, raw materials for the reactions that produce the constituents of photochemical smog. The stable portion consists of a constant geophysical level of methane from natural decay processes, and variable contributions of methane and other stable hydrocarbons from gas main leaks, sewage treatment, motor vehicle exhaust, and similar sources. The reactive hydrocarbons in the atmosphere result essentially from incomplete combustion and evaporation of organic compounds, of which the prime contributor is gasoline.

Most hydrocarbon substances are normally toxic only at concentrations of several hundred parts per million. However, a number of hydrocarbons can react photochemically at very low concentrations to produce irritating and toxic substances. There is no doubt that the atmosphere of many polluted areas contains hydrocarbons that are capable of producing, experimentally, cancer in animals.

Figure 15 presents the daily variation of total hydrocarbon levels for Newark, Washington, D.C., and Philadelphia. Methane concentrations are plotted for Philadelphia, the only city for which such data were available.

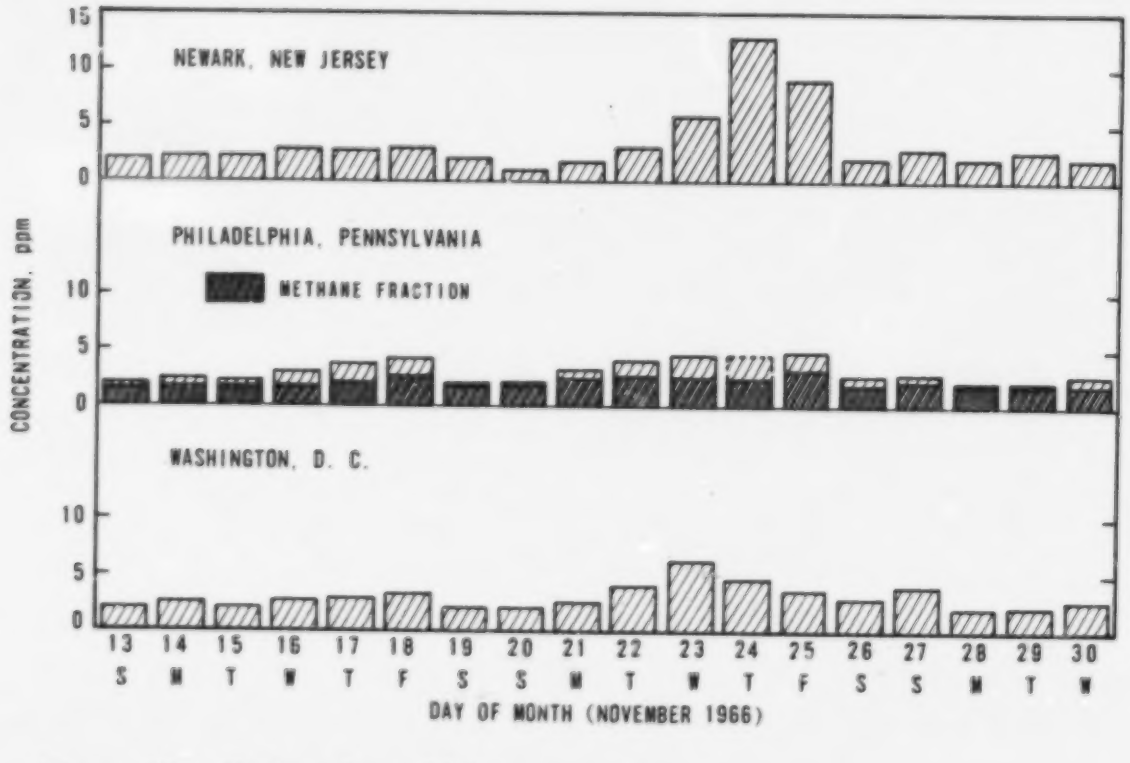

NEWARK, NEW JERSEY
PHILADELPHIA, PENNSYLVANIA
METHANE FRACTION
WASHINGTON, D. C.
CONCENTRATION, ppm
15
10
5
0
13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
S M T W T F S S M T W T F S S M T W
DAY OF MONTH (NOVEMBER 1966)

Figure 15. Hydrocarbons 24-hour mean values November 13 - 30, 1966, Newark, N.J.; Philadelphia, Pa.; and Washington, D.C.

One theory suggests that the methane concentration may be interpreted as an indicator of natural vertical ventilation. The methane concentrations, which are relatively constant from day to day, did rise on the days of restricted natural ventilation, i.e., on November 23 through 25. With improved ventilation conditions after the 25th, the levels of methane and total hydrocarbon returned to normal in all cities.

The pattern of diurnal variation (Figure 16) of total hydrocarbon shows a fairly consistent morning rise, which is coincident with the morning traffic surge, after which the level declines as a result of both reduced emissions and improved ventilation later in the morning. Since the concentration of the methane portion of the total hydrocarbons responds primarily to variations in the ventilation, the remainder, or non-methane, is responsible for the principal features in the diurnal patterns that correspond closely with patterns of traffic flow.

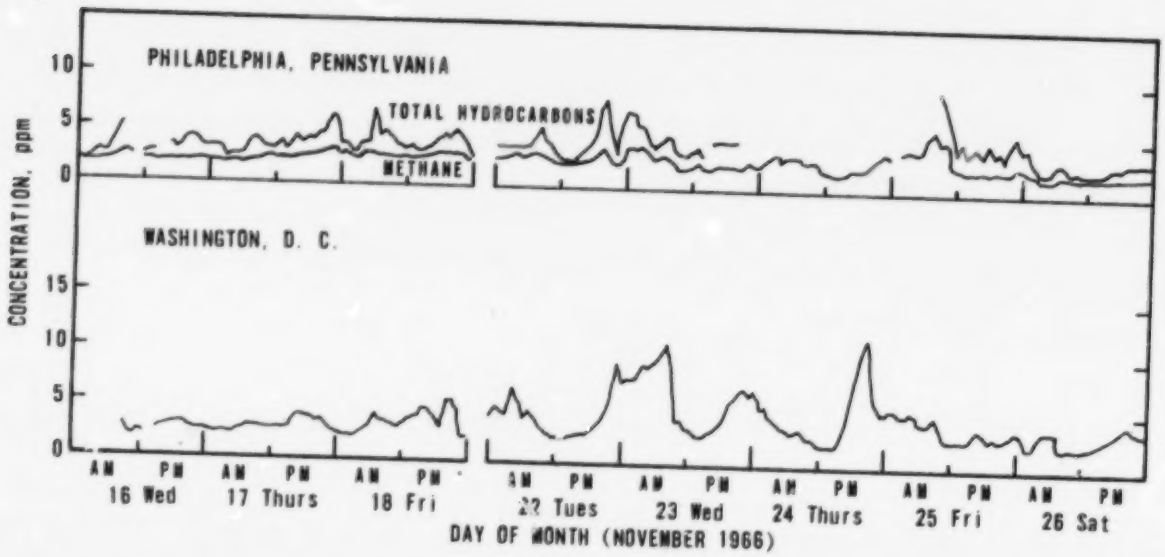


Figure 16. Hydrocarbons (diurnal variations)
November 16 - 18, and November 22 - 26, 1966
Philadelphia, Pa., and Washington, D.C.

Carbon Monoxide

Carbon monoxide (CO) is produced by the incomplete combustion of any organic fuel. Relatively complete combustion takes place in steam boilers and other fueled equipment that operates with an excess supply of air; however, the outstanding exception, the gasoline-powered internal-combustion engine, delivers the performance expected of it only when operated with slightly less

air than is needed to completely burn all hydrocarbons to carbon dioxide. The ubiquitous automobile is, therefore, the principal source of carbon monoxide.

Carbon monoxide is a toxic gas having the ability to replace oxygen that is in combination with hemoglobin in circulating blood. This characteristic may make it a health hazard to sensitive individuals even at levels found in the ambient atmosphere of most urban areas. In the passenger compartment of motor vehicles in traffic, carbon monoxide may reach levels sufficiently high to interfere with man's driving ability and thus pose a safety hazard in virtually any community.

The daily variation of mean levels of carbon monoxide is plotted in Figure 17. The same general pattern is evident here - a rise in the concentrations as the stable air mass settles over a metropolitan area, and a steadily downward trend as the clean air mass moves into the area.

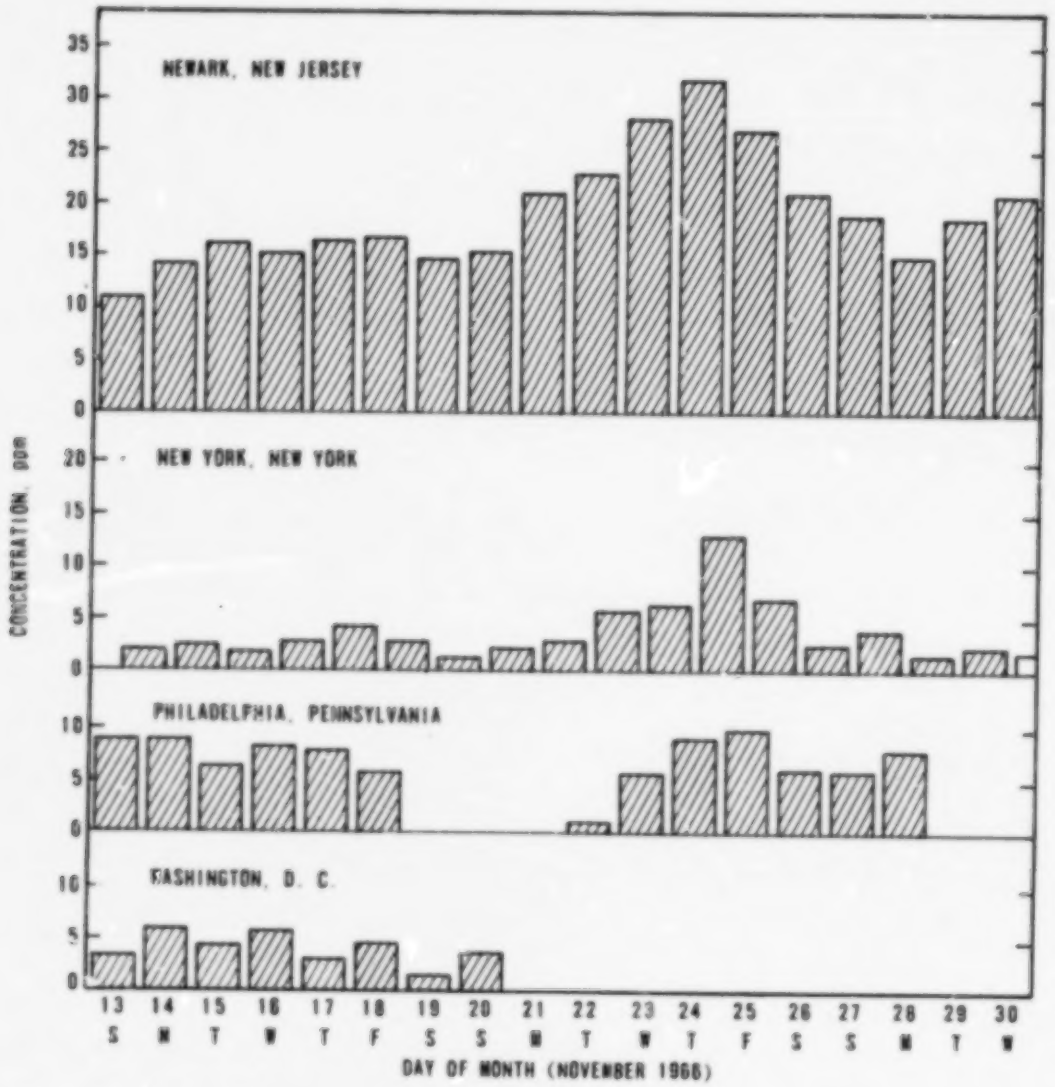


Figure 17. Carbon monoxide (CO) 24-hour mean values November 13 - 30, Newark, N.J.; New York City, N.Y.; Philadelphia, Pa.; and Washington, D.C.

Figure 18, the diurnal variation of carbon monoxide, is similar to the nitric oxide pattern (Figure 13). The carbon monoxide levels follow the traffic pattern with peaks in the morning and evening. Improved ventilation during the afternoon decreases the concentration at that time making the morning and evening peaks more prominent. Concentrations of this pollutant were much higher during the episode than during more normal periods. New York's peak value on November 24, for example, was 35 ppm, but on November 22 it was 8 ppm.

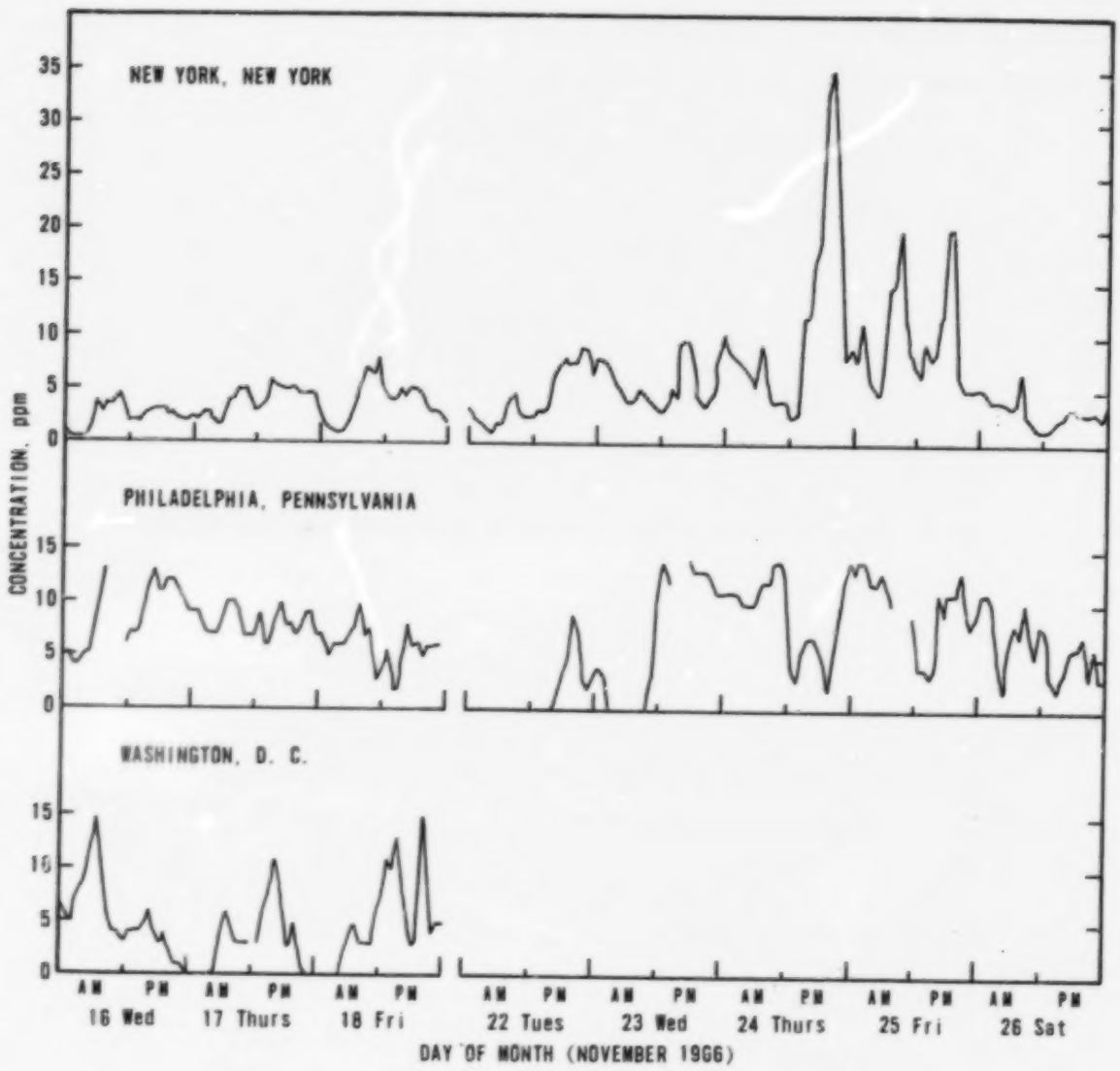


Figure 18. Carbon monoxide (diurnal variations) November 16 - 18, and November 22 - 26, 1966, New York City, N.Y.; Philadelphia, Pa.; and Washington, D.C.

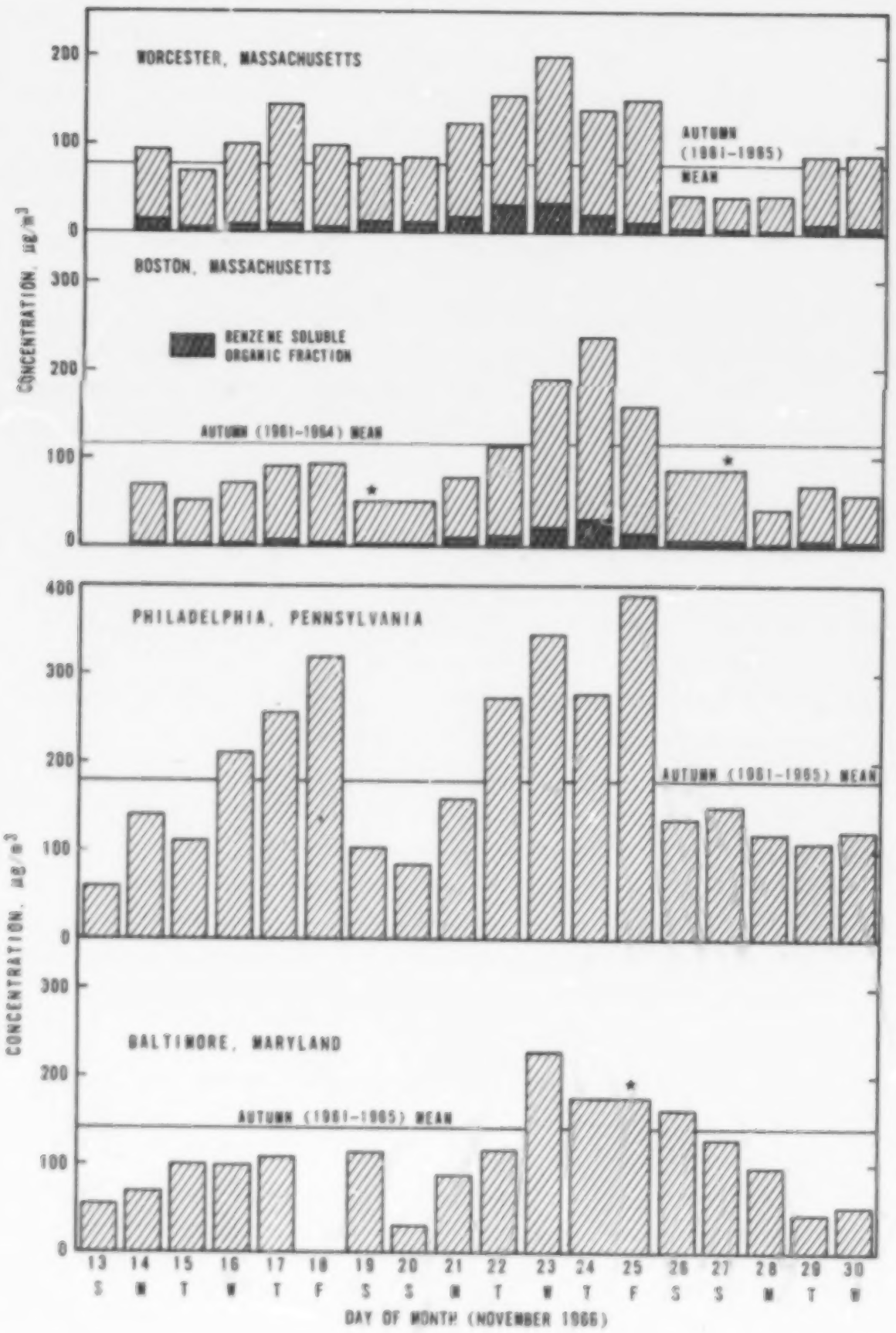
PARTICULATE POLLUTANTS

Particulates of solids, and occasionally liquids, constitute a relatively small (by weight) but important portion of polluted air in most cities and towns in the United States. These particulates may be either so large that they rapidly settle to the ground, or so small that they remain suspended in the air until they are removed by such a natural cleansing phenomenon as rain. Particulates may be quite complex in chemical composition. The organic materials found in airborne particles may contain aliphatic and aromatic hydrocarbons, acids, bases, phenols, and other compounds. Airborne particulates may also contain any of a side range of inorganic and metallic particles such as silica, lead sulfate, ammonium sulfate, aluminum, iron, lead, and copper. Sources of particulates include fuel combustion, including that of gasoline: various manufacturing and processing operations, including production of steel, cement, and petroleum products; and open burning and incineration of refuse.

Particulate air pollution is widely regarded as objectionable because it interferes with visibility, and is associated with soiling and corrosion of metals, fabrics, and other materials. Adverse effects on health from particulate air pollution are far more subtle, but are none the less significant. In general, concern about the health effects of particulates is related to (1) the ability of the human respiratory system to remove such particulate air pollution from inhaled air and retain it in the lung, (2) the presence in particles of mineral substances having toxic or other physiologic effects, (3) the presence of polycyclic hydrocarbons having demonstrated carcinogenic (cancer-producing) properties, (4) the demonstrated ability of some fine particles to enhance the harmful physiologic activity of irritant gases when both are simultaneously present in inhaled air, and (5) the ability of some mineral particles to increase the rate at which sulfur dioxide in the atmosphere is converted by oxidation to the far more physiologically active sulfur trioxide.[11]

Figure 19 presents the daily variation of total suspended-particulate levels and the autumn mean levels for the cities studied. Concentrations rose in all of the cities during the stagnation: however, only Philadelphia and Baltimore were in the advisory area. Concentrations definitely rose in Philadelphia during the preceding week, while levels in the other cities showed only a slight increase.

Levels recorded in Philadelphia, Worcester, and Boston represent multiple station averages. The maximum city-wide average concentrations in Philadelphia (390 $\mu g/m^3$), Worcester (198 $\mu g/m^3$), and Boston (238 $\mu g/m^3$) exceed maximum concentrations recorded for an autumn period since 1961 at the single-site National



* 48-hour total was averaged over the two days involved.

Figure 19. Suspended particulates (24-hour accumulation), Worcester, Mass.; Boston, Mass.; Philadelphia, Pa.; and Baltimore, Md.

Air Surveillance Network stations. These single-site maxima are 322 $\mu g/m^3$ for Philadelphia, 196 $\mu g/m^3$ for Worcester, and 209 $\mu g/m^3$ for Boston.

Measurements taken with AISI tape samplers represent a major source of information about air quality during the episode. These AISI samplers collect fine suspended particulates on a filter tape for consecutive 2-hour periods. The soiling capacity of the air drawn through the filter tape is determined by comparing the transmission of light through the sample and through the clean tape. The soiling index is reported in Coh units, the "coefficient of haze" per 1000 linear feet.

The daily variation in soiling index levels is presented in Figure 20. These patterns are more distinctive than the ones for the gaseous pollutants. Although Allegheny County, Wellsburg, Vienna, and Huntington were not included in the advisory, daily variations were very similar to those in the cities that were included. Peaks in the graph during the week preceding the episode show a similarity in the time of occurrence to the peaks for the gaseous pollutants.

Saturday-Sunday levels are usually lower than weekday levels for most pollutants; however in some cases (i.e., on November 26 and November 27) most pollutants appeared to be above average. This might have been caused by increased traffic as people returned home after the holiday.

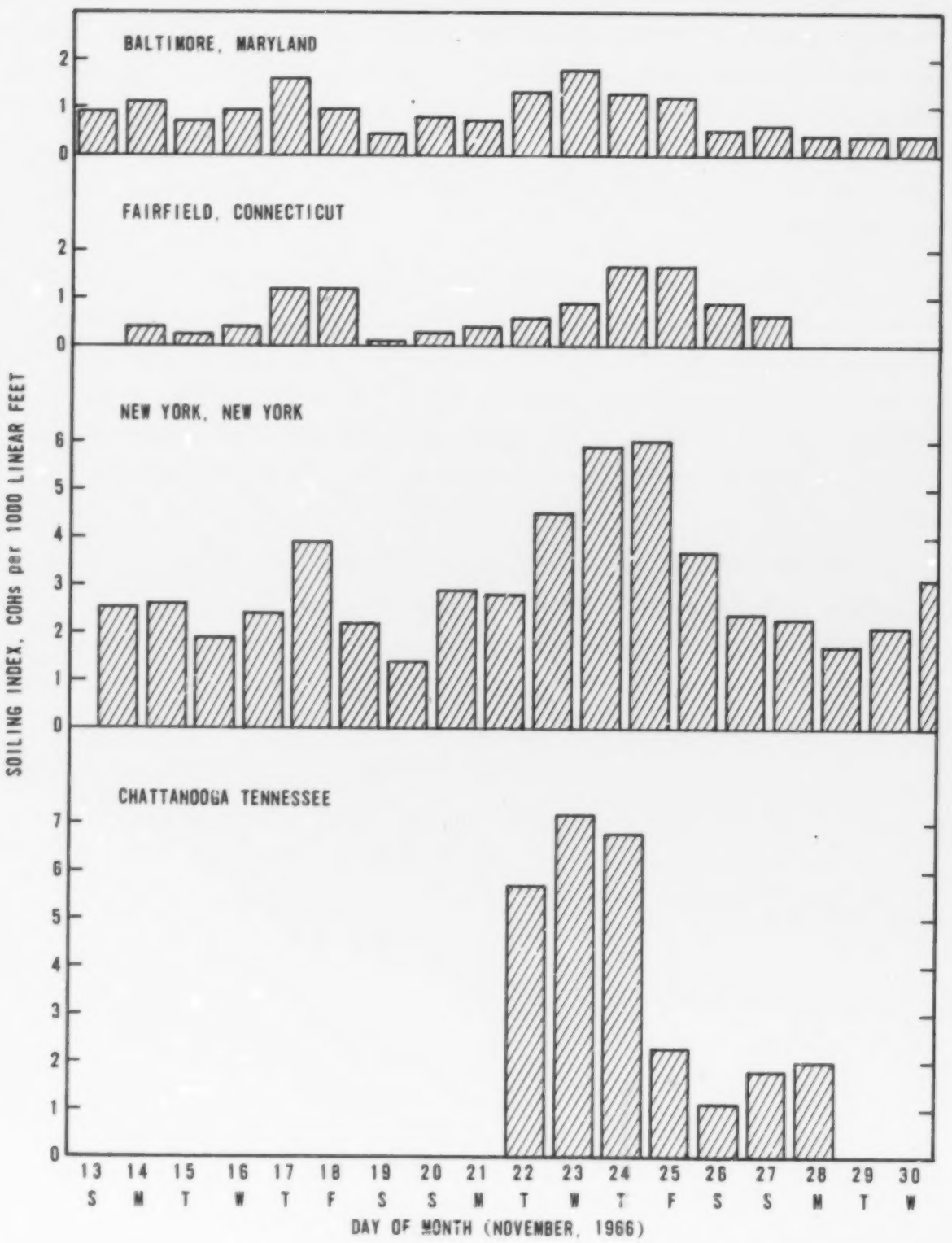

BALTIMORE, MARYLAND
FAIRFIELD, CONNECTICUT
NEW YORK, NEW YORK
CHATTANOOGA TENNESSEE
SOILING INDEX, COHs per 1000 LINEAR FEET
0
1
2
3
4
5
6
7
13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
S M T W T F S S M T W T F S S M T W
DAY OF MONTH (NOVEMBER, 1966)

Figure 20A. Soiling index ("coefficient of haze" per 1000 linear feet), 24-hour mean values, November 13 - 30, 1966, Baltimore, Md.; Fairfield, Conn.; New York City, N.Y.; and Chattanooga, Tenn.

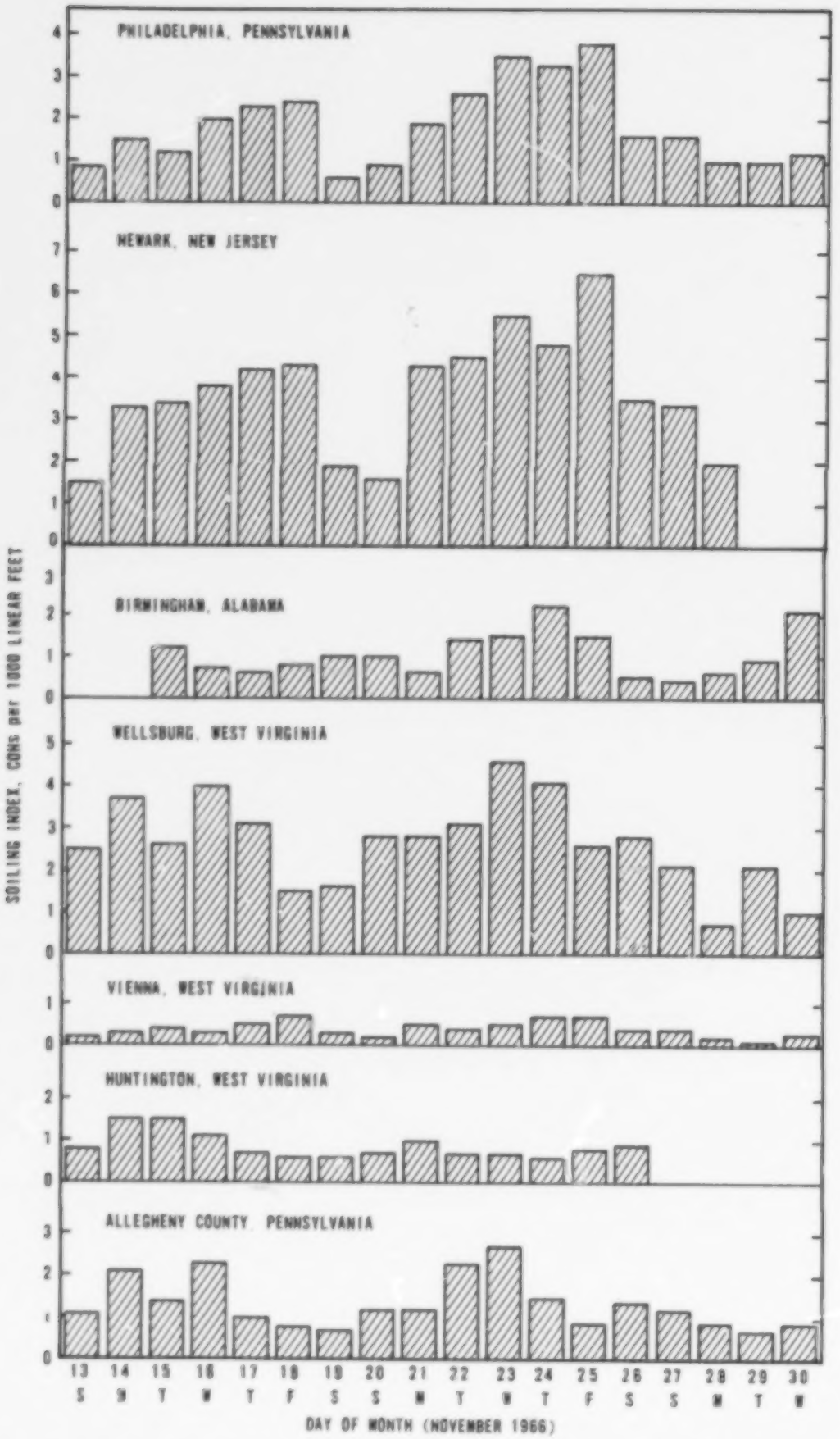


Figure 20B. Soiling index ("coefficient of haze" per 1000 linear feet), 24-hour mean values, November 13 - 30, 1966, Philadelphia, Pa.; Newark, N.J.; Birmingham, Ala.; Wellsburg, W.Va.; Vienna, W.Va.; Huntington, W.Va.; and Allegheny County, Pa.

SUMMARY AND CONCLUSIONS

This report has documented the Thanksgiving 1966 Air Pollution Episode in the Eastern United States in terms of the daily meteorology and ambient air quality. Analysis of the available air quality data indicates that the Air Pollution Potential Forecast Program (APPF) of the Public Health Service and the Weather Bureau did effectively forecast the stagnation. The increase in levels of the pollutants during the same period is indicative of stagnation regardless of the city considered. Advance warning is a necessary step to effective control. To effectively use APPF, municipalities must reduce emissions of air pollutants until meteorological conditions change to provide better ventilation for the affected areas. Monitoring and forecasting at local levels to augment the APPF is also needed.

A period of restricted natural ventilation on November 17 covered a small area and was short in duration, precluding it from generating an air pollution potential advisory. However, air quality did deteriorate significantly during this period; pollutant levels recorded in some cities approximated peak concentrations during the subsequent episode.

In general, public concern about air pollution (as judged by publicity) is minimal except during those periods when the conditions of restricted natural ventilation are sufficiently extensive to warrant issuing an air pollution potential forecast. Public attention must be focused on the fact that there are additional periods when local conditions can effect a comparable deterioration of community air quality.

As in other documented air pollution episodes, the high levels of air pollution in the eastern United States during the period from November 24 through 30, 1966, created adverse health effects. Researchers in New York City found an increase in death rate of approximately 24 deaths per day during the period. Recently published information indicates that periods of high air pollution not considered "episodes" may also be associated with increased mortality.[12]

APPENDIX: METEOROLOGY AND DISPERSION OF AIR CONTAMINANTS

Many of man's activities result in the introduction into the air of substances, which are detrimental to his own health and well-being. Until fairly recently the ocean of "clean" air has been proportionately large enough that, except for some small local areas, pollutants were quickly diluted to insignificant levels. A constantly increasing population, which adds pollutants both directly and indirectly, has resulted in the frequent incapability of atmospheric dispersion to maintain acceptable air quality. In a large sense the dispersion of pollution in the atmosphere is only a temporary measure, because pollutants must eventually either be removed from the air by various natural processes or accumulate indefinitely on a world-wide basis. Although removal mechanisms have been studied, they are poorly understood at present. For example, no mechanisms for the destruction or removal of carbon monoxide in the atmosphere have been found.

DILUTION AND DISPERSION

A situation involving the constant rate of emission of smoke from a stack illustrates the effect of horizontal dilution. For example, a doubling of wind speed from one period to another doubles the volume of air into which the smoke is emitted, and the concentration of smoke is reduced by a factor of 2 (Figure 21A). In general, a stronger wind disperses pollutants more widely. However, high winds blowing over tall stacks and tall buildings can produce eddies on the lee sides that will bring the stack emissions to the surface with almost no dilution. On the other hand, emissions from tall stacks can be dispersed widely by light winds, which provide ample dilution, before reaching surface levels (see Figure 21B).

Vertical dispersion depends on the degree of stability of the atmosphere. An understanding of the physical reasons for atmospheric behavior requires some familiarity with the gas laws of Boyle and Charles. Essentially, these laws state that when the pressure on a parcel of gas changes there will also be a change in the volume and temperature. Atmospheric pressure changes with elevation. At sea level the pressure averages 14.7 pounds per square inch, but at about 18,000 feet above sea level the pressure is reduced by a factor of 2. According to the gas laws, this reduction of pressure with increasing elevation is suf-

ficient to lower the temperature 5.4°F for each 1000-foot increase in elevation, which defines the specific temperature gradient known as the dry adiabatic lapse rate. When the vertical change in temperature of the atmosphere matches the dry adiabatic lapse rate, then it is said to be in the neutral condition with respect to stability. The temperature of any parcel of air that is moved vertically will also change at that rate and, as a result, will be indistinguishable from the air that surrounds it.

Different degrees of stability result from the departure from the neutral or dry adiabatic lapse rate. The isothermal condition, in which the temperature does not change with elevation, is a stable condition. Even more stable is the situation wherein the temperature rises with an increase in elevation. This is the "inversion" condition, so named because it is the inverse of the general change in temperature that is found in the atmosphere.

Under stable conditions the winds at upper levels have little interaction (no vertical interchange) with those at lower levels. Winds near the surface are usually weaker than winds at upper levels because of friction with the earth's

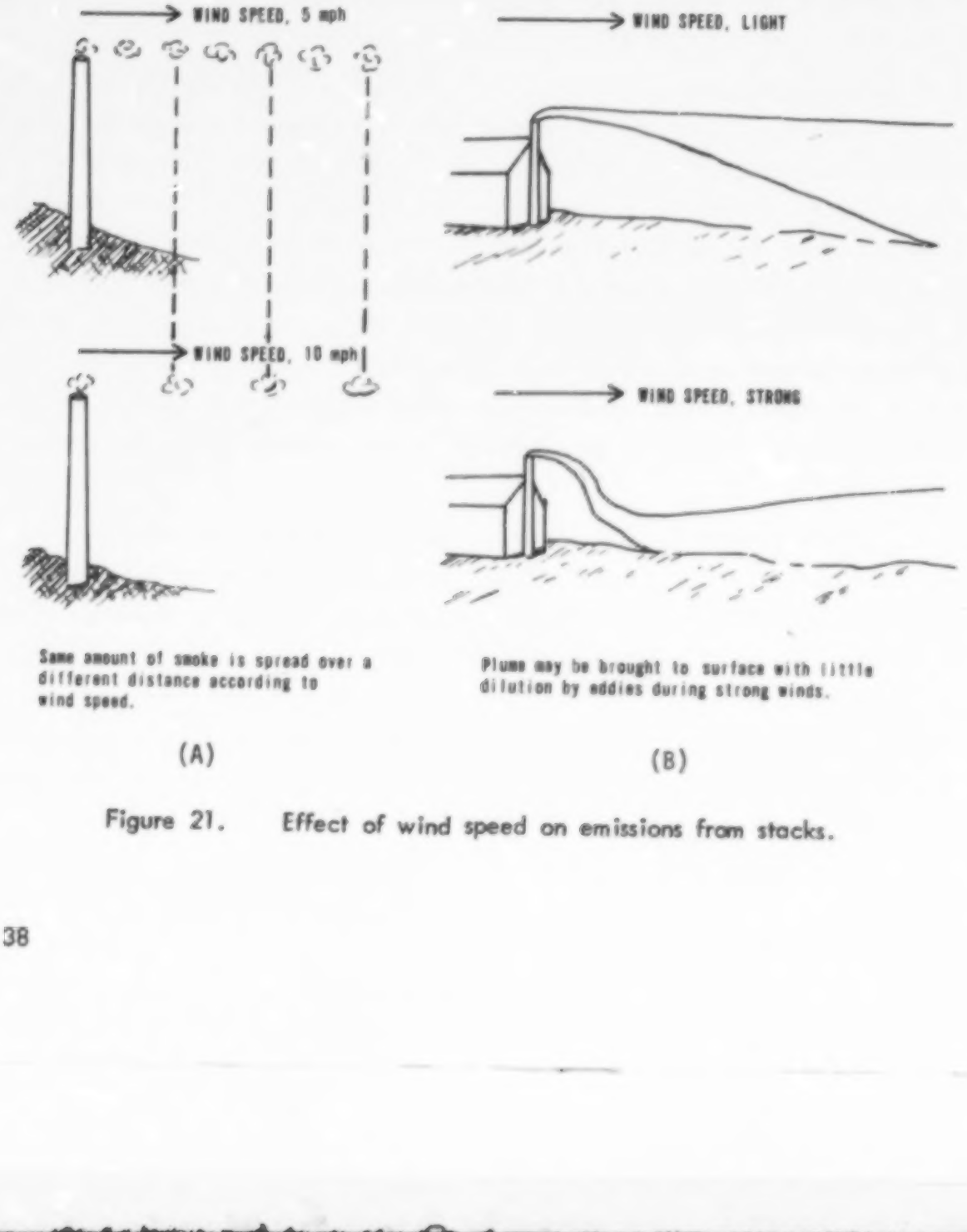

WIND SPEED, 5 mph
WIND SPEED, 10 mph
WIND SPEED, LIGHT
WIND SPEED, STRONG
Same amount of smoke is spread over a different distance according to wind speed.
Plume may be brought to surface with little dilution by eddies during strong winds.
(A)
(B)

Figure 21. Effect of wind speed on emissions from stacks.

surface. Less lateral movement reduces the horizontal dispersion of pollutants so that, under stable conditions, concentrations of pollutants usually build up rapidly. Vertical mixing is also restricted during stable conditions.

The neutral condition is unusual. The lapse rate of the atmosphere ordinarily is less than 5.4°F temperature change per 1000-foot elevation change. In such a case, a parcel of air that is lifted will be cooler at the new level than the air surrounding it. Because it is cooler, it will be more dense and will tend to return to its original position. If it returns to its original position, it will regain its previous temperature (and density) and be in equilibrium. Air moved to a lower level would become warmer than the air surrounding it. With a relatively warmer temperature, it would be less dense and would tend to rise to its former level. This tendency of a parcel of air to return to its original level exemplifies a stable condition.

An unstable condition occurs when the temperature decrease with height is greater than the dry adiabatic lapse rate. In this case a parcel of air that is lifted will be warmer than the temperature of the surrounding air at the new level. A parcel of air that is displaced downward will become cooler than the air around it. The accompanying change in density in both cases then causes the parcel of air to move even farther away from its original position. Unstable layers are not unlimited. They are always bounded by either the earth or stable layers of air, and the accelerating force eventually meets resistance and vertical motion stops. During unstable periods vertical movements are accelerated, and pollutants are well mixed throughout the unstable layer. Horizontal mixing is usually improved because wind speeds near the surface are likely to be greater. In general, wind speeds aloft are greater than those near the surface, but under unstable conditions the surface winds will be nearly as strong as those aloft.

DIURNAL PATTERN OF DISPERSION CAPACITY

Changes in stability usually occur as the result of local heating or cooling of the lower levels of the atmosphere. Although temperatures of the upper levels do change, larger changes are on a seasonal basis with smaller day-to-day changes, and relatively small hour-to-hour changes. The hour-to-hour temperature change at the surface, however, is much larger. On clear days, incoming solar radiation warms the earth's surface rapidly, and on clear nights outgoing radiation cools the surface. The surface layer of air is warmed or cooled by contact with the earth's surface. Enough air movement to circulate this air vertically to some extent is always present. A cooled layer may be only a few feet deep on a quiet night, and sometimes is evident visually in the

form of a ground-hugging fog layer. At other times the comparatively cool layer may be several hundred feet thick. This situation, labeled "inversion," occurs when the air aloft is warmer than the air below. It does not matter whether the air aloft becomes warmer or the surface air becomes cooler, the end result of relatively warm air above cooler air is the determining factor, indicating stable conditions. Pollution emitted into the stable layer will remain within the layer, which is frequently the case in the early morning. After sunrise, as the ground is heated, the air in contact with the ground is warmed, becomes less dense, and rises, somewhat as a bubble rises in a liquid, to the elevation where its density is equal to that of the air around it. These rising currents carry heat from the surface that eventually raises the temperature of a thicker and thicker layer of air. This circulation of air also carries the pollution, which has been released into it at lower levels, to greater and greater heights. The level to which these currents penetrate is called the "mixing depth." The distribution of pollution to higher levels has the added advantage of better horizontal dilution, in addition to vertical dispersion, because wind speeds at the upper levels are likely to be greater.

The diurnal change in surface temperature with lower temperatures at night and higher temperatures during the day produces changing lapse rates, which affect the stability of the air. Ordinarily, during each day the nocturnal stability is replaced by daytime instability. Although pollution concentrations may become high during the overnight stable period, pollution will usually be widely dispersed during the unstable period associated with the daylight hours. The daytime dispersion usually results in little carry-over of pollution from one day to the next.

STAGNATIONS

Under certain situations carry-over of pollution may occur from one day to the next. In the area covered by an anticyclone only the very lowest levels may warm enough during the daytime hours to reach the unstable condition that helps in the dispersion of pollution. In this restricted depth (often 1000 feet or less), the concentration of pollutants will remain high. An anticyclone, or "high-pressure system," is so named because a greater mass of air over an area will cause a barometer, which measures the weight of the air above it, to rise to a "higher" reading. The air should not be thought of as being piled higher over that spot, but as being cooler and denser and having a greater mass. Because the pressure is higher in the area of the high, air flows out from it at the surface toward places of lower pressure, and air from above settles to replace it. This deep layer of settling air warms throughout

at 5.4°F per 1000 feet of settling to create relatively warm air aloft over a wide area. Warm air aloft indicates stability; and in the case of a high, not only the surface level, but also a layer many thousands of feet deep may become stabilized.

When a high covers an area, a double threat of increase in pollution concentration exists. The usually clear skies and light winds that accompany a high are conducive to surface-based nighttime radiation inversions that are overlaid by other stable layers due to the subsiding air of the high. Even if the nighttime surface inversion is destroyed during the day by surface heating, there is still no break-through from the surface into a vigorous cleansing air stream. The stable air aloft in a subsiding high generally is sluggish in its horizontal movement and continues to resist vertical movement from below. Because the pollution is not completely carried away, a portion of one day's pollution is added to the next, and concentrations of pollution increase to obnoxious and dangerous levels.

FORECASTING STAGNATIONS

When an attempt is made to forecast a potential for high air pollution because of weather conditions in a given area, several objective parameters are checked by the air pollution potential forecasters. The height to which mixing will occur (mixing depth) and the average speed of winds through this mixing depth are calculated by electronic computers, using data obtained from all the upper air (radiosonde) observation stations in the United States. Data on current morning conditions collected at 1200 Greenwich time (0700 EST) are used in these calculations. Forecasts are then made of mixing depth and average wind speed for the current afternoon and the afternoon of the following day. The product of the mixing depth and the average wind speed through the mixing depth is called the "ventilation."

Observations indicate that no stagnation of consequence will occur if the "ventilation" during the afternoon hours exceeds 6000 cubic meters per second or if the average wind speed is greater than 4 meters per second (about 9 miles per hour). Once these criteria for minimum ventilation and wind speed are met, forecasters must then consider other parameters.* If the appropriate conditions are found over an area of at least 75,000 square miles (roughly the size of Oklahoma), and appear likely to persist for at least 36 hours, a potential for air pollution is considered to exist and a forecast message delineating the area is prepared for use by air pollution and public health agencies.

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*The presence of precipitation or the imminent approach of a frontal system automatically excludes an area from the high pollution potential forecast.

REFERENCES

1. Firket, J. (Secretary): Sur les causes des accidents survenus dans la vallee de la Meuse, los des brouillards de December 1930. Bull. Acad. Roy. Med. Belg. 11:683-741, 1931.

2. Schrenk, H. H., et al. Air Pollution in Donora, Pa. Epidemiology of the Unusual Smog Episode of October 1948. Public Health Bulletin No. 306, Federal Security Agency, Washington, D. C., 1949.

3. Ministry of Health: Mortality and Morbidity During the London Fog of December 1952. Report by a Committee of Department Officers and Expert Advisers appointed by the Minister of Health. Reports on Public Health and Medical Subjects, No. 95, H. M. Stationery Office, 1954.

4. Fog and Frost. British Med. J. 2:1626 (Dec. 15) 1962.

5. Greenburg, L., et al. Report of an Air Pollution Incident in New York City, Nov. 1953. Public Health Report 77:7-16 (Jan.) 1962.

6. Scott, J. A. The London Fog of December 1962. Med. Officer 109:250, 1963.

7. Greenburg, L. Air Pollution Episode in New York City in 1963, read before the 58th Annual Meeting of the Air Pollution Control Association, Toronto, Canada, June 20-24, 1965.

8. Air Quality Criteria for Sulfur Dioxides. DHEW, PHS. March 1967.

9. Hearings before the Committee on Interstate and Foreign Commerce, House of Representatives. U.S. Government Printing Office, 1967.

10. Lynn, D. A., Steigerwald, B. J., and Ludwig, J. H. The November-December 1962 Air Pollution Episode in the Eastern United States. PHS Publ. No. 999-AP-7. 1964.

11. Air Pollution - 1966, Hearings before a Subcommittee on Air and Water Pollution of the Committee on Public Works, United States Senate. U.S. Government Printing Office, 1966.

12. Greenburg, L., et al. "Report of an Air Pollution Incident in New York City, November 1963." Public Health Reports 78:1061-64.

SELECTED BIBLIOGRAPHY

Miller, M. E. and Niemeyer, L. E. "Air Pollution Potential Forecasts — A Year's Experience." Journal of the Air Pollution Control Association 13:205-210 (1963).

Meetham, A. R. Atmospheric Pollution. Pergamon Press. pp. 266-272. 1956.

Simpson, C. L. Some Measurements of the Deposition of Matter and Its Relation to Diffusion from a Continuous Point Source in a Stable Atmosphere. HW-69292 Rev. Richland, Washington. 1961, 22 pp.

Niemeyer, L. E. "Forecasting Air Pollution Potential." Monthly Weather Review 88:88-96 (March 1960).

Boettger, C. M. "Air Pollution Potential East of the Rocky Mountains: Fall 1959." Bull. Amer. Society 42:9 (September 1961), pp. 615-620.

Korshover, J. "Synoptic Climatology of Stagnating Anticyclones." SEC Technical Report A60-7, Robert A. Taft Sanitary Engineering Center (Cincinnati: 1960).

Holzworth, G. C. "Estimates of Mean Maximum Mixing Depths in the Continuous United States." Monthly Weather Review 92:5 (May 1964) pp. 235-242.

Hosler, C. R. "Climatological Estimates of Diffusion Conditions in the United States." Nuclear Safety 5:2 (Winter 1963-64).

Miller, M. E. "Forecasting Afternoon Mixing Depths and Transport Wind Speeds." Monthly Weather Review 95:1 (January 1967) pp. 35-44.

Davis, Francis K. and Newstein, Herman. "Meteorological Analysis of November 1966 and January 1967 Air Pollution Episodes in Philadelphia," read before the 60th Annual Meeting of the Air Pollution Control Association, Cleveland, Ohio, June 1967.

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